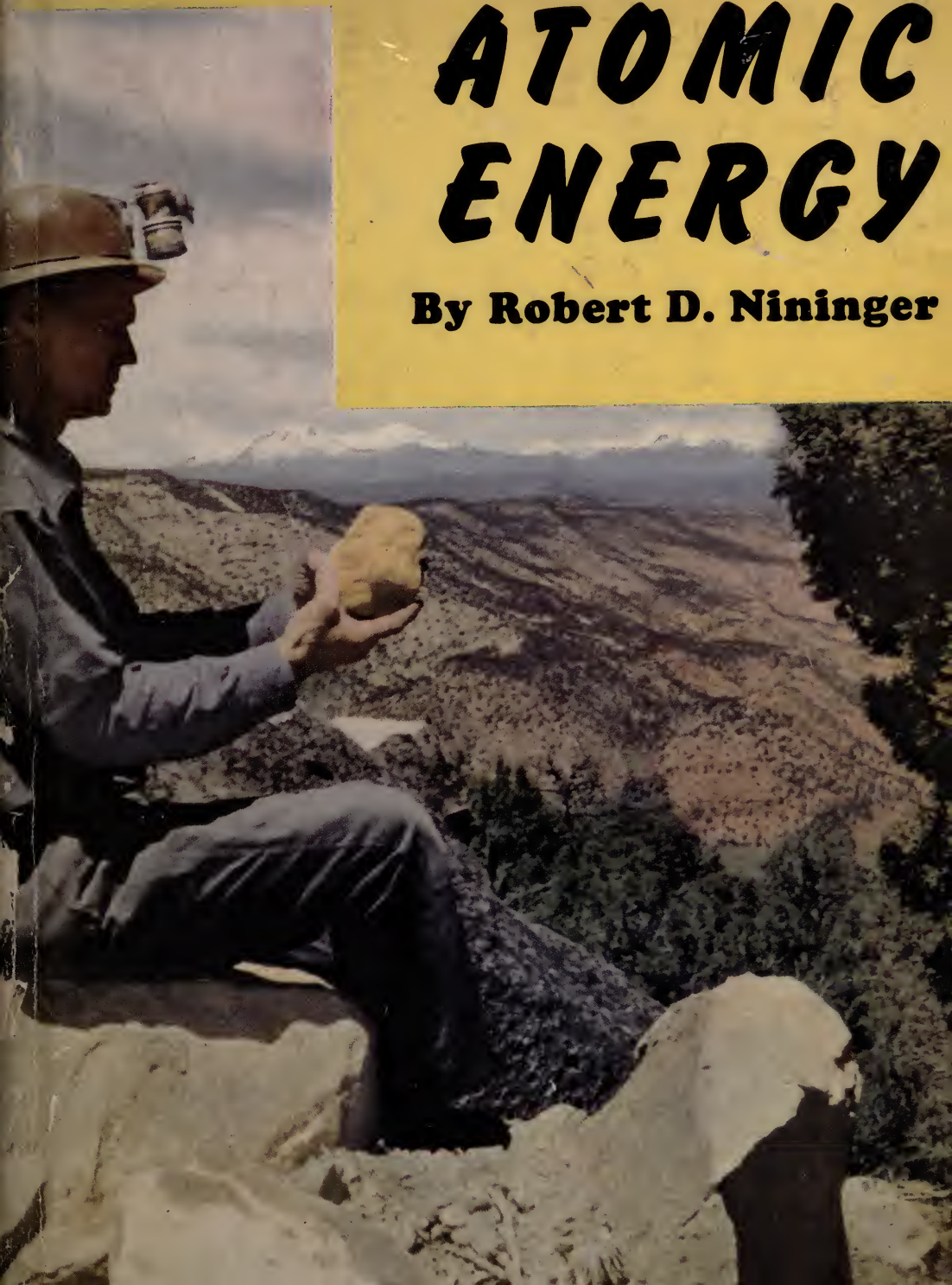


MINERALS *for* **ATOMIC** **ENERGY**

By Robert D. Nininger



MINERALS FOR ATOMIC ENERGY

Gray

This is a complete handbook to prospecting for atomic energy minerals, written by the Deputy Assistant Director for Exploration of the Atomic Energy Commission.

It covers with authority the geology of these minerals, their presently known and probable incidence in this country and abroad, their identification in nature; the tools, equipment and methods to use in exploration and the evaluation of the results of successful searching. Comprehensive illustration in color and black and white aid the presentation.

The organization of the contents is designed to make the book equally useful to the untrained and the professional geologist or prospector. Part One describes the minerals and mineral deposits that are the sources and potential sources of uranium, thorium and beryllium, with full attention to physical properties and geologic characteristics, together with a careful description of the identifying marks of likely deposits. Part Two is a comprehensive survey of the various areas of the world with respect to their favorability for new deposits of atomic energy minerals with particular attention to the United States. Part Three covers prospecting equipment and techniques, the use of the Geiger and scintillation counters, evaluation of deposits, and the countless details of prices, markets and governmental controls the prospector must know. Extensive appendices include mineral identification tables, classifications of ore deposits, testing and analysis procedures, lists of equipment suppliers and analysis centers, the laws and regulations controlling prospecting here and in the important areas abroad, and other pertinent information.

Deposits of atomic energy minerals, once thought rare and isolated, are being found with increasing frequency in unexpected areas. The growth of atomic energy uses for peace-time purposes, in power, propulsion, use of isotopes, and in countless forms of research, is growing steadily, and peace-time atomic science, depending on continuing supplies of raw materials, promises to be one of the expanding miracles of this century. It is within the capabilities of any informed prospector to aid in the search, and to help his fellow-man as well as himself in doing so.

Norman T. and Helen K. Gray

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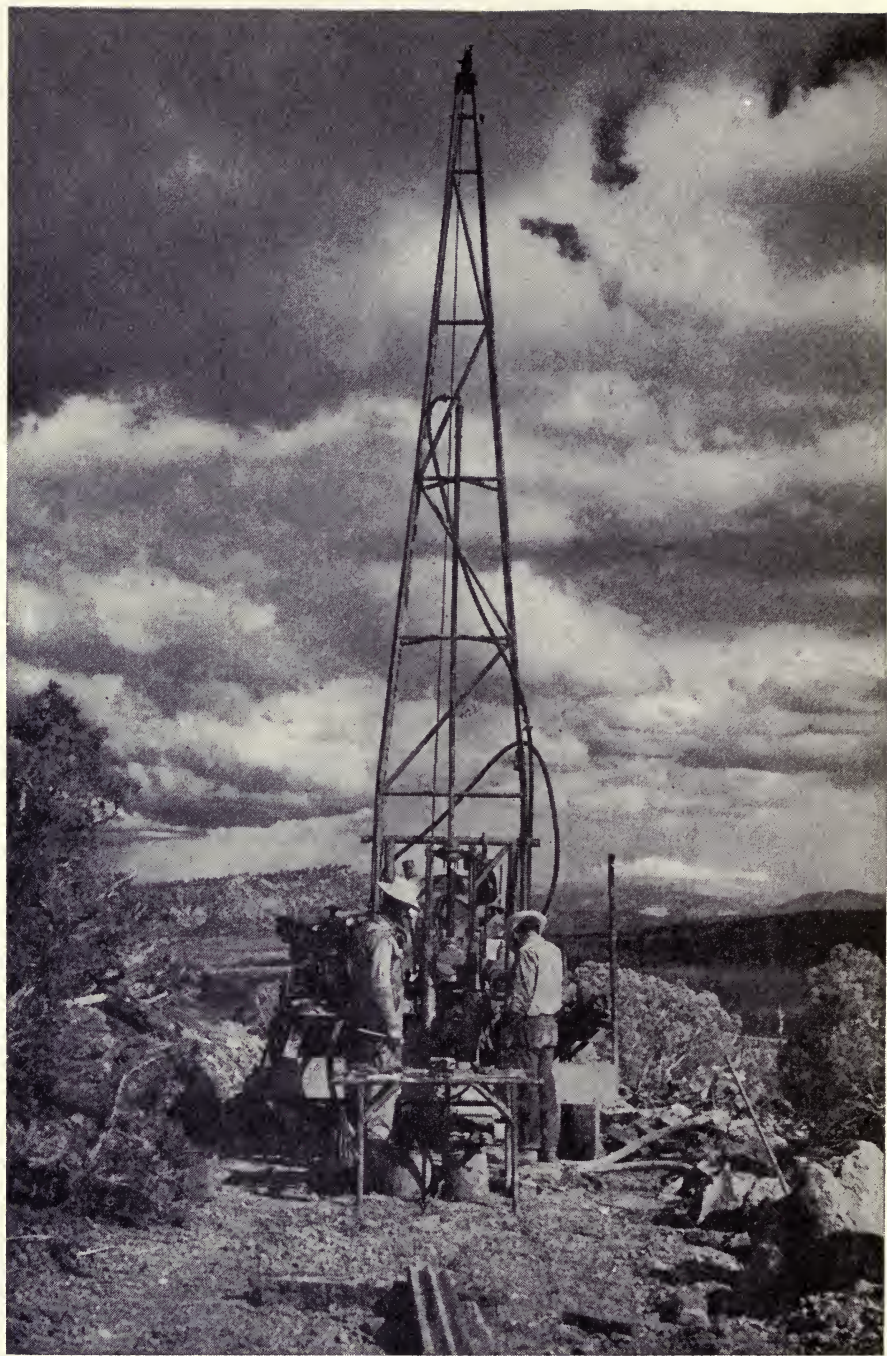
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MINERALS FOR ATOMIC ENERGY



Diamond Drilling on the Colorado Plateau.
Courtesy Union Carbide and Carbon Corp.

MINERALS FOR ATOMIC ENERGY

A GUIDE TO EXPLORATION FOR URANIUM, THORIUM, AND BERYLLIUM

ROBERT D. NININGER

*Deputy Assistant Director for Exploration
Division of Raw Materials
United States Atomic Energy Commission*



D. VAN NOSTRAND COMPANY, INC.

TORONTO

NEW YORK

LONDON

NEW YORK

D. Van Nostrand Company, Inc., 250 Fourth Avenue, New York 3

TORONTO

D. Van Nostrand Company (Canada), Ltd., 25 Hollinger Rd., Toronto

LONDON

Macmillan & Company, Ltd., St. Martin's Street, London, W.C. 2

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Published simultaneously in Canada by

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Library of Congress Catalogue Card No. 54-10377

PRINTED IN THE UNITED STATES OF AMERICA

PREFACE

When the curtain of secrecy was first lifted from the atomic energy program, much was written about the large amounts of energy that could be theoretically produced from uranium and other radioactive elements. It was soon a widely held opinion that this huge atomic program was based on very small quantities of uranium worth fabulous sums. A review of the technical literature also revealed that uranium was very widely dispersed throughout the earth's crust and that almost all natural substances exhibited some radioactivity. Quickly the idea spread that almost anyone had a chance to get rich quick by finding uranium, literally in his own back yard. Although founded on a basic misconception, this "boom" did serve a useful purpose in arousing public interest in the search for uranium. In spite of the fact that uranium is not consumed in amounts comparable to iron, copper, or lead, its need is measured in tons rather than pounds, and the demand for it is greater than the presently available supply.

During the first three years of its existence, the Atomic Energy Commission received more than 15,000 inquiries and more than 20,000 samples representing practically every natural substance (and some that weren't natural). Many of these inquiries concerned the "back yard" possibility, and many of the samples came from back yards.

Other questions revealed equally serious misconceptions concerning the properties of naturally radioactive substances. Among other things, radioactivity from supposed deposits of uranium was blamed for making cows lose their hair, stopping watches, and for causing burns, fires, and a ringing in the ears.

Other questions, however, were quite sound and to the point:

"I have pitchblende on my land. What shall I do with it?"

"How much is uranium ore worth?"

"Is the Atomic Energy Commission interested in thorium?"

"Where can I sell my uranium ore?"

"Do I need a license to mine uranium?"

"How do I stake a mining claim?"

As a result of these inquiries, the Atomic Energy Commission in cooperation with the U. S. Geological Survey published a booklet in 1949 called *Prospecting for Uranium*. This booklet treated briefly the subject of uranium prospecting and in one section answered specific questions of the type most commonly asked by the public.

PREFACE

The purpose of this book is to expand and complete, as nearly as possible in one volume, the average interested person's knowledge of the occurrence of uranium and the methods employed in searching for it, as well as similar information on two other elements specifically related to atomic energy—thorium and beryllium.

An important phase of the Atomic Energy Commission's exploration program involves providing information to the prospector in order to make his search more effective. The author has attempted here to summarize and present in practical and largely nontechnical form this information which has been distributed in pamphlets, reports, speeches, papers, booklets, and letters, together with other basic information required for successful prospecting for atomic energy minerals. The extensive appendix is intended to provide the specific detailed information on various aspects of the subject for the "working" prospector and those others who want to "know all there is to know." The text of the book is divided into three parts: (I) What to look for, (II) Where to look, and (III) How to look, which should be read in that order by those not familiar with the subject. For others, however, each part and individual chapters within the parts may be read separately.

The author has attempted to make *Minerals for Atomic Energy* both interesting and readable to the layman and sufficiently comprehensive for use by professional prospectors, geologists, and engineers, and high school and college science students. It is written not only in an attempt to help and encourage those who are already "combing the hills" for uranium and other "atomic" raw materials, but in the hope of enticing others to join the search. Hence, its dedication to all those who are optimistic concerning the part atomic energy will play in the future of America and mankind; to the new "forty-niners" who, like their ancestors, are quick to see and take up the challenge of each new frontier and who, seeing the tremendous potentialities of atomic energy, also recognize the challenge of supplying the raw material for its development.

R. D. N.

New York, N. Y.
July, 1954

ACKNOWLEDGMENTS

In a work of this nature, dealing as it does with information developed as a result of the largest and most intensive mineral exploration program ever undertaken—in which have participated hundreds of geologists, mining engineers, mineralogists, and prospectors, both government and privately employed—it is impossible to record adequately and specifically the author's indebtedness to the multitude of sources of information used. Acknowledgments have been omitted in the text for reason of simplicity, but the author hereby gratefully acknowledges the contributions of the following as well as of all others not specifically mentioned who have added to the knowledge of the subject:

George W. Bain, Amherst College; John W. Gruner, University of Minnesota; Paul F. Kerr, Columbia University; Charles F. Davidson, United Kingdom Geological Survey; James Cameron, formerly U. K. Geological Survey; A. H. Lang, Geological Survey of Canada; Norman Fisher, R. S. Matheson and C. J. Sullivan, Bureau of Mineral Resources, Commonwealth of Australia; S. B. Dickinson and R. Sprigg, South Australia Department of Mines; H. H. Adler, Margaret Cooper, Helen V. DeSanctis, Philip H. Dodd, R. W. Edmonds, Donald L. Everhart, E. K. Judd, Muriel M. Mathez, Phillip L. Merritt, E. V. Reinhardt, Ernest E. Thurlow, Thomas N. Walthier, and Robert J. Wright, U. S. Atomic Energy Commission; E. N. Cameron, Henry Faul, Richard P. Fisher, M. Fleisher, J. J. Glass, G. B. Gott, Lowell Hilpert, R. H. Jahns, E. P. Kaiser, R. U. King, J. D. Love, Vincent E. McKelvey, John B. Mertie, Jr., John M. Nelson, James J. Norton, Lincoln R. Page, Frank W. Stead, Alice Weeks, Doris Blackman Weir, V. P. Wilmarth, and Donald P. Wyant, U. S. Geological Survey; E. J. Carlson, M. H. Kline, A. A. McKinney, U. S. Bureau of Mines.

The author also wishes to express his appreciation for the cooperation extended by officials of the following organizations:

United States Atomic Energy Commission.

Atomic Energy Control Board of Canada.

Department of Mines and Technical Surveys, Canada.

Eldorado Mining and Refining, Ltd., Canada.

Department of Atomic Energy, United Kingdom.

Atomic Energy Division, Geological Survey and Museum, United Kingdom.

Australian Atomic Energy Commission.

Bureau of Mineral Resources, Australia.

ACKNOWLEDGMENTS

Department of Mines, South Australia.

Commissariat de l'Energie Atomique, France.

The author is further indebted to H. H. Adler, Margaret Cooper, Donald L. Everhart, Royal S. Foote, Thomas E. Gillingham, E. K. Judd, Muriel Mathez, and Robert J. Wright, for help on specific portions of the text, and to John V. Beall, Duncan Clark, Donald L. Everhart, Rafford L. Faulkner, and David P. Kuntz for reviewing the manuscript.

Permission from O. C. Smith, for the use of illustrations and for the direct reproduction of material on mineral identification techniques, is acknowledged with thanks. Data on minerals were obtained largely from the following publications:

Mineralogy of Uranium and Thorium Bearing Minerals, D'Arcy R. George, RMO-563, U.S.A.E.C., Technical Information Service, Oak Ridge, Tenn., 1950.

Geology of Uranium Deposits—A Condensed Version, Donald L. Everhart, with Mineral Tables by Muriel Mathez, U.S.A.E.C., 1951.

Identification and Qualitative Chemical Analysis of Minerals, 2nd. Ed., O. C. Smith, D. Van Nostrand Company, Inc., 1953.

Regulations concerning location of mining claims in the Western States in Appendix X were compiled by Paul Martin, Counsel, Grand Junction Operations Office, U. S. Atomic Energy Commission.

The author wishes to thank Margaret and Glenn Huss for typing and editing the manuscript, and Catherine Engelke, Rhoda Kaplan, Elvira Morace, Emily Walker, and Jeanette Weaver for stenographic and drafting help.

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THE PROSPECTOR IN THE NEW ERA OF ATOMIC ENERGY

Prospecting is an ancient and honorable art. The desire to find and extract from the earth raw materials from which to fashion implements that can be used to provide a less rigorous and more bountiful life has been one of mankind's most basic and impelling desires from the time of the cavemen to the present.

In the beginning, the raw materials that could be utilized were limited to stone for building, gems, and those elements that occurred in metallic form like copper, silver, and gold. In nearly all cases the first use of the non-precious metals was in weapons, and requirements for their manufacture could be easily met from readily accessible sources. Gradually, however, primitive smelting techniques were developed that permitted the extraction of iron, lead, mercury, and an increasing number of other metals from simple, high-grade ores, and new uses were discovered to increase the demand for these metals and the effort needed to meet it. The prospector then came into his own—a necessity to the maintenance of everyday life.

Progress in utilization of metals was, nevertheless, slow through the centuries until the Industrial Revolution suddenly developed demands so great that prospecting became an industry in itself. This industry reached its maturity with the industrial development of the United States in the latter half of the nineteenth century and the beginning of the twentieth century, when the demand for mineable metals required a prospecting program of tremendous proportions throughout the entire world. The success of this effort in meeting the ever-increasing demands for new and greater quantities of raw materials can be measured by the amazing industrial progress and, unfortunately, by the fantastic waste of materials in war during the past hundred years. United States consumption of iron ore in 1943 was more than 100,000,000 tons in contrast to less than 30,000,000 in 1900; copper, 1,600,000 tons in contrast to 200,000; and lead 1,000,000 tons in contrast to 300,000.

At 8:14 A.M. on August 6, 1945, at Hiroshima, the era of atomic energy began and with it a new chapter in the history of the metals industry and the prospector. Consistent with past history, the principal raw material of atomic energy—uranium—was used first in the form of a weapon. But the potential destructiveness of atomic energy and its equally impressive possibilities for

MINERALS FOR ATOMIC ENERGY

peaceful development precluded any gradual and uncontrolled development like that involving iron, copper, lead, and the other basic materials of modern civilization. The Congress of the United States recognized this difference when, by the Atomic Energy Act of 1946, it established the Atomic Energy Commission with powers and responsibilities exceeding those of any agency ever before established by the federal government. Congress made this statement of policy:

The effect of the use of atomic energy for civilian purposes upon the social, economic, and political structures of today cannot now be determined . . . It is reasonable to anticipate, however, that tapping this new source of energy will cause profound changes in our present way of life. Accordingly, it is hereby declared to be the policy of the people of the United States, that subject at all times to the paramount objective of assuring the common defense and security, the development and utilization of atomic energy shall, so far as practicable, be directed toward improving the public welfare, increasing the standard of living, strengthening free competition in private enterprise and promoting world peace.

This general view of the importance of atomic energy has been shared widely throughout the world, nearly every country having enacted specific legislation or executive controls concerning its development. Many countries have substantial atomic research and development programs. At least eight countries other than the United States—Belgium, Canada, England, France, Holland, Norway, Sweden, and the U.S.S.R.—operate or are constructing uranium reactors. England and the U.S.S.R. have successfully developed atomic weapons.

The atomic energy program in the United States, which was begun in 1942, and the continuance and expansion of which were provided for by the establishment of the Atomic Energy Commission in 1946, now represents a total investment by the American people of more than twelve billion dollars and an annual operating cost of more than one billion dollars. The principal objective of this tremendous effort must be, for the present, the defense of the free world. However, the tremendous potentialities for peacetime uses so wisely recognized by Congress, many of which are already being realized as by-products of the weapons program, assure a continuance of the atomic energy program, perhaps on a scale undreamed of today. It is safe, therefore, to predict that the demand for the raw materials of atomic energy and the role of the prospector in supplying them will be no less permanent than they are for iron, copper, lead, and all the other essential raw materials of modern civilization; and there is every reason to believe that at least for the foreseeable future the importance of this demand and its fulfillment will exceed that of any other single problem.

Much has been said and written since 1945 about the brilliant scientific discoveries by eminent physicists of many nations, the wonderful accomplishments of the technicians in applying them, and the tremendously successful

THE PROSPECTOR IN THE NEW ERA OF ATOMIC ENERGY

undertakings of the American atomic energy program—and many deserving awards have been made to representatives of these groups by an admiring public. But as important and, in fact, amazing as these accomplishments have been, the publicity given to these more spectacular aspects of the program has served to direct attention from one basic, incontestable fact: without the basic raw material—uranium—which must be won by the sweat of man's brow from the earth, none of this could have been achieved; and not without uranium and the other raw materials of atomic energy, such as thorium and beryllium, which may well play an increasingly important part, can the program continue to provide a means of defense and the hope of a more abundant life.

Because until recently the raw materials of atomic energy were relatively unimportant, there was little incentive to look for them, and because they were not looked for intensively, as were iron or copper or gold, few deposits were found. As a result, not only were adequate supplies of uranium unknown when the era of atomic energy burst upon us, but we did not know where or how to look for additional supplies. The uncertain future will not allow us the normal time for the accumulation of this information. Thus the Atomic Energy Commission has been faced with the problem of trying to compress a hundred and fifty or more years of exploration and discovery of raw material supplies into ten or fifteen years.

Uranium, discovered in the eighteenth century, for more than one hundred years was known first for its use as a coloring agent and then as an undisposible by-product of the radium industry and later of the vanadium industry. Thus, those deposits of uranium known at the beginning of the atomic era were primarily sources of other materials, or they were found by accident in the search for copper in the Belgian Congo, for cobalt and silver in the Northwest Territories of Canada, for gold and vanadium in Colorado, and for silver in Czechoslovakia. Thorium, a possible important source of fissionable material in the future, and beryllium, an important structural and moderating (neutron-controlling) material¹ in present-day uranium reactors and future atomic power plants, have been among the host of "minor metals" considered to be of only limited usefulness during the past fifty or sixty years and always on the sidelines of the great prospecting effort for the major base and precious metals.

The rapid development of the mining industry in the United States is an excellent example of the successful operation of a private enterprise system

¹ A neutron is that part of an atom with no electrostatic charge which, together with the positively charged proton, makes up the nucleus. Neutrons are emitted from the splitting of uranium atoms in reactors and are the "triggers" which explode other uranium atoms, thus causing the chain reaction. In certain types of reactors the velocity of the neutrons must be slowed down. Materials which are effective in slowing down neutrons are called "moderators."

MINERALS FOR ATOMIC ENERGY

and the important role of the individual prospector in meeting the demand for raw materials. The history of this industry illustrates the importance of the smallest economic units in the early stages of the development of natural resources. Large capital investments have been made by the mining industry to develop known sources of raw materials, and huge expenditures have been applied to major exploration efforts in known favorable areas; but the bulk of the original discoveries has been made by prospectors. In most cases, also, the initial development has been begun by small groups of individuals willing to invest their relatively small capital in a speculative venture with an opportunity for large rewards. The private enterprise of industry, research and educational institutions, and of the individual prospector, geologist, and engineer is essential to the success of any raw material exploration and development program. This is as true of uranium as it is of iron and copper; and there is no reason to believe that, with the proper stimulus of profit and freedom of operation for the prospector and the mining industry, the discovery and development of uranium will not follow the same course so successfully demonstrated in the case of other metals.

During the war the necessity for secrecy in the atomic energy program made this approach to the problem of uranium exploration impossible. In order to keep from the enemy the knowledge of the tremendous effort of the United States, England, and Canada to develop an atomic bomb, a realistic, and what has since been proved to be a more successful, program of exploration for uranium was sacrificed. The search for new sources of uranium was carried out exclusively by carefully screened army officers, civilian employees of the Manhattan Project, and a very limited number of geologists and engineers recruited by a few selected mining companies under contract with the government. The secret was kept, but, although the personnel engaged in the wartime effort performed amazing feats of forcing theretofore unheard of quantities of uranium from the mines of the Congo, Canada, and the western United States in time to meet the required production schedule, thus forming the groundwork for the present program, not a single *new* source of uranium was brought into production.

After the end of the war the veil of secrecy began to be lifted, and in 1948 the Atomic Energy Commission inaugurated a major uranium exploration and development program based upon the full-scale participation of the mining industry and the prospector. It was recognized that no government-operated exploration program, even assuming that hundreds of the most competent geologists and mining engineers were available, could substitute for these private activities. Therefore, the Commission concentrated on the development of incentives and the dissemination of information which would encourage private activity in the field of exploration for uranium deposits.

THE PROSPECTOR IN THE NEW ERA OF ATOMIC ENERGY

Dr. John K. Gustafson, then Director of Raw Materials for the Commission, stated before the American Mining Congress in San Francisco on September 23, 1948:

The Commission firmly believes that the discovery, development, and production of uranium ores by and large can best be accomplished by competitive private enterprise under the stimulus of profits. Our objective is to get you into the atomic energy business on that basis.

The essential points in this program were the establishment of guaranteed minimum prices for uranium ores and refined products, and the establishment of a bonus for the discovery and development of new deposits of uranium ores. These price schedules and the bonus have been continually reviewed and have been amended and enlarged to meet changing conditions and the increased need for uranium.

Because the Commission and its predecessor, the Manhattan District, had been the sole searchers for uranium, the Commission possessed the great preponderance of knowledge on the subject. For this reason, and because it was necessary to speed up uranium exploration beyond what might be expected from industry alone, as well as to help industry and the prospector get into the program, the Commission continued and expanded its own exploration effort.

The relationship of this program to the activities of private enterprise is twofold. One major aspect could be compared to the function of the geologic and engineering staffs of major companies and their relation to the development of discoveries of raw materials made by individual prospectors and small mining organizations. The other major phase might be compared to the role of the long-established government agencies such as the U. S. Bureau of Mines and the U. S. Geological Survey—namely, to provide basic information and to sponsor research to add to the knowledge to be drawn upon by private enterprise.

The present critical defense uses for uranium have required that the Commission's exploration program be maintained at a high level. This activity has not had the objective of substituting for the discovery and development of uranium ore supplies by private industry, but rather has been directed toward stimulation of a much more rapid rate of private development by supplying the supporting information and services required.

Mr. Jesse C. Johnson, director of the Commission's Division of Raw Materials, made the following statement in a speech before the American Institute of Mining and Metallurgical Engineers in Mexico City on October 31, 1951:

The history of the mining industry, and the limited experience with government prospecting, clearly point to the need of enlisting the efforts of the thousands of private prospectors, geologists, and mining engineers who are out looking for all types of

MINERALS FOR ATOMIC ENERGY

mineral deposits. To obtain the type of effort which everywhere has been responsible for mineral development, it is necessary to provide the same incentive—the opportunity for rich returns. That means an attractive price for the ore and the right to claim and work a deposit which might be found. The effort a prospector puts forth to find a mineral deposit cannot be bought for day wages; the risk capital required to develop a prospect is not available merely for the chance of earning a 4% return. In mining, particularly prospecting and development, the risks are great and the rewards must be commensurate.

The policy of enlisting private industry in exploration for atomic energy minerals required an intensive program of disseminating information on the occurrence of these minerals to the mining industry, to prospectors, and to the public in general, and of advertising the existence and meaning of the established incentives. The Commission has established a wide, regular distribution of geologic and research reports to industry and professional groups and makes available to the public circulars, reprints, and copies of speeches describing the occurrence of minerals for atomic energy, the Commission's exploration program, and its buying program for uranium.

As a result of this program, important new areas of uranium mineralization have been found at Marysvale, Utah; at several locations in Wyoming; at Grants, New Mexico; in the Boulder area of Montana; in southwest South Dakota; and in several previously unproductive districts of the Colorado Plateau area. The manner in which the original discoveries were made in these areas would appear to substantiate the basic soundness of the Commission's over-all exploration policy, for they were made not by geologists employed by the government, but by prospectors and mining companies who had been alerted to the importance of uranium, the existence of a market for it, and the means of identification of deposits.

Mr. Johnson was apparently well justified in stating in 1950, "I am convinced that the prospector, like the infantryman, is not outmoded. We still need the prospector to find mineral deposits. The geologist's technical knowledge is no substitute for the optimism and persistence of the prospector. . . ."

Such success has, of course, encouraged even greater participation by private enterprise until now more than one hundred mining companies, including many of the largest companies, are actively engaged in uranium exploration, and literally tens of thousands of prospectors—professional and amateur—are combing the hills. Five years ago this effort was described as "the gold rush of 1949," and it has since grown many times larger.

Members of the Commission, officials of the Departments of State and Defense, leaders of Congress, and the President of the United States have repeatedly stated that, as long as the present dangerous international situation exists, the need for increasing supplies of atomic weapons and the development of additional military applications of atomic energy will continue. This has

THE PROSPECTOR IN THE NEW ERA OF ATOMIC ENERGY

been seconded by the government leaders of most of the other countries of the free world. It follows that there is a continuing need for increased private participation in the uranium exploration program in order to expand as rapidly as possible the supply of this critical material. Fortunately, the development of new and improved atomic military applications and techniques involves the expansion of basic scientific knowledge which can and will be used to bring closer to reality the tremendous civilian possibilities of atomic energy. The military stockpiles of fissionable material derived from the uranium discovered by the prospector can be used for peaceful purposes if the military danger should subside. There is no doubt that atomic energy is here to stay, and so is the opportunity for the "atomic prospector" to strike it rich.

PART ONE

WHAT TO LOOK FOR:
URANIUM, THORIUM, AND BERYLLIUM;
THEIR MINERALS AND DEPOSITS

I

INTRODUCTION

Since this is a book about *minerals for atomic energy*, it would be well to begin by defining those minerals. This book concerns the basic raw materials for the atomic energy program—the minerals¹ of uranium, thorium, and beryllium. Without these minerals the program either could not exist or would be seriously handicapped. The demand for them, whether for military or for peaceful applications of atomic energy, now exceeds, or may well exceed in the future, the known supply.

Nearly all substances have some application in the atomic energy program; and some, like iron, copper, nickel, and even gold, silver, and platinum, are used in relatively large quantities. But the atomic energy program is only one of many large consumers of those elements,² and an adequate supply is readily available. The basic raw materials or minerals required for atomic energy are needed, or may be needed, in such quantities as to require a special effort to obtain them, since it happens that these minerals most critical to the atomic energy program are also those for which there was little use fifteen years ago, and no substantial supply had been developed.

The minerals that will be discussed here, then, are those that contain in significant amounts the rare and heretofore little used elements that are essential to, or are particularly important in, the process of atomic fission, the basis for atomic weapons, atomic power, and the many useful by-products of atomic energy; they are the minerals from which are extracted uranium, thorium, and beryllium.³

Uranium and thorium are also referred to as *source materials*. The term *source material* is peculiar to the atomic energy program and may be considered a legal term. It originated with the Atomic Energy Act of 1946 (Public Law 585—79th Congress), by which the Congress of the United States provided for the Atomic Energy Commission. Congress defined source material as “uranium,

¹ *Mineral*: An individual inorganic substance, with specific physical properties, occurring in nature and containing one or more elements which can be extracted from it.

² *Element*: The simplest substance having specific chemical and physical properties; composed of atoms of one kind.

³ Zirconium, a fourth important element in atomic energy development, is not included because it presents no raw material supply problem.

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thorium, or any other material which is determined by the Commission, with the approval of the President, to be peculiarly essential to the production of fissionable materials; but includes ores only if they contain one or more of the foregoing materials in such concentration as the Commission may by regulation determine from time to time." Pursuant to the Act, the Commission defined source material as "any material, except fissionable material, which contains by weight one-twentieth of one per cent (0.05 per cent) or more of (1) uranium, (2) thorium, or (3) any combination thereof." The minerals of uranium and thorium fall within the category of source materials.

Congress defined *fissionable material* as "plutonium,¹ uranium enriched in the isotope 235,² any other material which the Commission determines to be capable of releasing substantial quantities of energy through nuclear chain reaction of the material, or any material artificially enriched by any of the foregoing."

Uranium is by far the most important source material, and without it there would be no atomic energy program. As a result, uranium is the major target of the Commission's exploration program today, and the uranium minerals are the primary subject of this book. With the exception of a few hundred pounds licensed annually by the Commission for other essential uses, uranium is used solely in the atomic energy program.

Thorium, the second source material, is only potentially important as a practical source of fissionable material. Its importance for other than atomic energy purposes is greater than uranium, since it has been used widely in the fabrication of gaslight mantles for more than fifty years, and in more recent years in industrial chemical processes. It is also a by-product of the processing of the mineral monazite for a variety of rare elements called *rare earths* used in carbon arcs, lighter flints, high-temperature metal alloys, and optical glass manufacture. Thorium minerals, therefore, may be valuable both for thorium and for the rare earths that they usually contain.

The Atomic Energy Commission explained the extent and nature of its interest in thorium in a press release on October 14, 1948, as follows:

¹ *Plutonium*: Plutonium is a fissionable element with chemical properties differing from those of uranium, which is produced artificially in a "pile" by the bombardment of uranium-238 with neutrons. An operation of this type is carried out at Hanford, Washington. The fissionable materials, uranium-235 and plutonium, can be used to make weapons and to release energy which can be converted to power.

² *Isotope*: One of one or more varieties of an element having the same chemical properties but differing in atomic weight. The fissionable isotope 235 is found in natural uranium in the proportion of one part in 140 parts. It is chemically nondistinguishable from uranium-238, but can be separated from it by several means based on the slight difference in weight. The great gaseous-diffusion plants at Oak Ridge, Tennessee, and elsewhere, are for this purpose.

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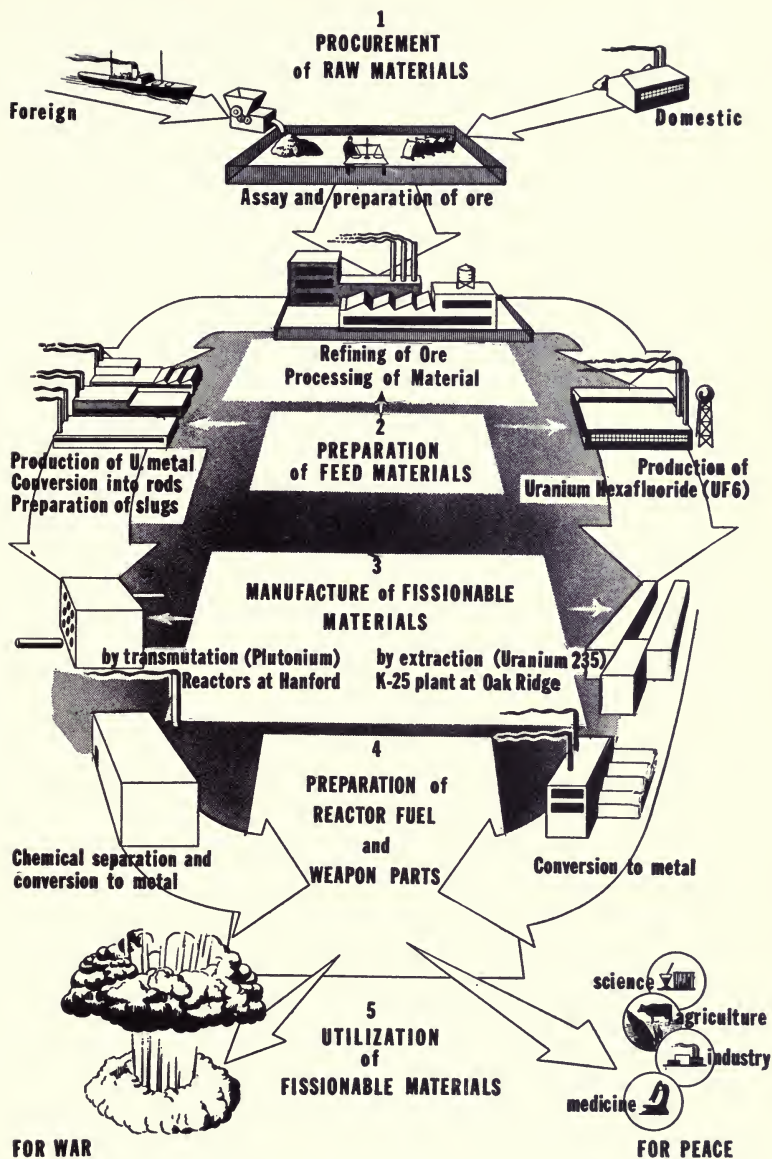


PLATE I. Production of Fissionable Materials. Courtesy U. S. Atomic Energy Commission.

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While a strict control of exports and a complete record of domestic movements of thorium-bearing materials, including monazite ore, is maintained by the Commission, pursuant to the Atomic Energy Act of 1946, the usefulness of thorium and its principal source in nature, monazite ore, so far as the Commission's program is concerned, is limited for the present time to research. Accordingly, the only thorium the Commission purchases is for experimental purposes, chiefly in the form of thorium salts, and the Commission has no purchase program for monazite ore as such.

Thorium has long been recognized as a potential source of fissionable material. Consequently, like uranium, it was placed under the control of the Atomic Energy Commission by the Atomic Energy Act of 1946. Solving the many complex research problems in the way of the large-scale utilization of thorium may take a decade or two. The possibility, however, cannot be excluded that the time may be shorter. When the research problems are solved, thorium may become of great significance in the atomic energy program. Until these problems have been solved, however, thorium will not be in large demand for use in nuclear reactors.

The potential importance of thorium arises from the fact that it is possible to derive a second fissionable isotope of uranium, uranium-233, from thorium in a manner similar to the derivation of plutonium from uranium. Thus, there is the possibility that, in the future, thorium could approach uranium in importance in the utilization of atomic energy. Uranium-233 was classified a fissionable material by the Commission in April 1948.

Since both uranium and thorium minerals are radioactive and therefore both react to the counter, and because they are frequently found together, it is well for the prospector to be acquainted with the thorium minerals even though he may be primarily concerned with the search for uranium.

Beryllium is not a source material and is not radioactive. It is, however, of considerable importance to the atomic energy program. Because of its property of slowing down, but not absorbing, neutrons and its favorable heat transfer characteristics, very light weight, and high melting point, it is extremely useful as a structural material and moderator for high-efficiency piles that may be used in the future for the production of commercial or military power. Beryllium also has important commercial uses both for peace and war. Beryllium-copper alloy, containing about 2 per cent beryllium, is extremely malleable and ductile and resistant to "fatigue" and corrosion; it has been used widely in springs and in nonsparking tools. The largest defense use is in the manufacture of certain parts for aircraft engines and in springs for instruments and other parts of ships, tanks, and guns. Because of the very important defense uses, as well as the use in atomic energy development, beryllium ore has been in short supply, prices are high, and increased prospecting for new sources is important. Its importance to atomic energy development fully justifies the inclusion of beryllium-bearing minerals among minerals for atomic energy.

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URANIUM

Uranium is the last of the naturally occurring elements in the Periodic Table (Atomic No. 92) and the element with the greatest atomic weight (238). It has a specific gravity¹ of about 19 compared to 19.32 for gold and 7.85-7.88 for iron. However, unlike gold, it is never found in its free metallic state in nature, but rather is combined with other elements to form minerals. Uranium is the only element which has a naturally occurring, readily fissionable form—the isotope uranium-235. The proportion of uranium-235 in natural uranium, one part in about 140, has not been known to vary regardless of the type of mineral or deposit in which the uranium is found.

Uranium is widely distributed throughout the earth's crust with minute amounts present in nearly every type of rock,² as well as in natural waters, including sea water. Its estimated average concentration in the earth's crust as a whole is about 0.0003 per cent or about three grams per ton of rock; in sea water about one gram per thousand tons.

In spite of what appear to be very small figures for the abundance of uranium, they compare with those for other important elements. Uranium is more abundant than gold, platinum, silver, bismuth, mercury, cadmium, and antimony; it is approximately equal in abundance to tin, arsenic, and molybdenum; slightly less abundant than cobalt; and about one-sixth as abundant as lead, one-tenth as abundant as zinc and tungsten, and one-thirtieth as abundant as copper.

On the other hand, there is not necessarily any direct relationship between the relative abundance of an element in the earth's crust and its present availability for man's use. In the latter respect, uranium appears to fall far behind many of the other elements listed above. This probably results in part from the relatively short period during which uranium has been sought in any urgent sense. Many important commercial deposits undoubtedly exist that have not yet been found, and techniques have not yet been developed to extract uranium from other deposits that are known. The unusual susceptibility of uranium to solution, transportation, and diffusion throughout the earth's crust may also be partly responsible for the apparently small number of large, rich concentrations. This characteristic is particularly frustrating to the uranium prospector, because he is continually teased by attractive looking occurrences of uranium which, after investigation, may prove to be of no commercial value.

¹Specific gravity is the weight of a substance relative to water, which has a specific gravity of one (1.0).

²A rock is defined as a particular mass or formation of one or more minerals occurring in nature. The earth's surface beneath the soil is composed of a variety of rocks, in turn composed of different combinations of minerals.

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Uranium has an affinity for oxygen. It is not known to occur as a native element or as an arsenide, sulfide, or telluride—common associations of other metals—but occurs most commonly in combination with oxygen to form oxides, phosphates, sulfates, vanadates, arsenates, carbonates, and silicates.

Uranium occurs in more than one hundred different minerals. Of this very large number of uranium minerals, only relatively few occur in economic concentrations and will be sought by the prospector, professional or amateur, interested in financial gain. The remaining minerals are of scientific interest or have value as collectors' items, and will be sought by the "rock hounds" with just as keen an interest. Some of these other minerals, too, may eventually be found in commercial quantities, and in the meantime the study of them is continually increasing our knowledge of the habits of uranium, thus aiding in the long run the principal problem of increasing our uranium supplies. This majority of noneconomic uranium minerals has still another importance that must not be overlooked by the prospector—they are the proof of at least some uranium mineralization in an area, and, with some exceptions, the best place to look for a uranium mine is where uranium is known to exist.

Descriptions of the uranium minerals will be found in Chapter III and in Appendix I. A Radioactive Minerals Identification Table is provided in Appendix III.

THORIUM

Thorium has the atomic number 90 and an atomic weight of 232; its specific gravity is 11.7. It is a heavy, gray, hard-to-fuse metal belonging to the titanium group. Unlike uranium, thorium does not have a natural fissionable isotope; but, when bombarded by neutrons, thorium becomes uranium-233, which is a fissionable material. Therefore, thorium may be called a "fertile" material because, although it is nonfissionable, it can be made into a fissionable material.

Like uranium, thorium is distributed widely in nature but in relatively small amounts. It is estimated that the thorium content of the earth's crust is about 0.001 per cent (ten grams per ton of rock) or three to four times that of uranium. It is thus more abundant than tin, arsenic, molybdenum, and the precious metals, equal in abundance to beryllium and cobalt, and about half as abundant as lead, one-fourth as abundant as zinc, and one-tenth as abundant as copper.

Although thorium is more abundant than uranium and does not have the chemical properties that permit ease of movement and wide dispersion through the surface rocks of the earth after original deposition, important high-grade deposits of thorium are even scarcer than those of uranium. On the other hand, thorium has not yet been subjected to the intensive search that has been

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conducted for uranium in the past six years, and, like uranium, it was not subject to large demand in the past.

Traces of thorium have been found in more than 100 minerals, including most of those containing uranium. Only a few, however, contain in excess of 1 per cent thorium. Although some of these are relatively common, they are generally too disseminated throughout the rocks of the earth to be potential primary sources of the metal. However, the properties which make thorium minerals, unlike uranium, resistant to chemical decomposition, permit the thorium minerals to keep their identity through the weathering and erosion processes which eventually destroy most rocks and a large majority of minerals. Thus, thorium minerals are often reconcentrated by stream or wave action in river channels and on ocean beaches along with other resistant minerals, such as quartz, garnet, zircon, magnetite, ilmenite, and gold, in what are known as placer deposits. In certain areas, thorium-bearing minerals have been sufficiently concentrated by weathering and erosion processes to form deposits of commercial importance.

The most common thorium-bearing minerals were originally constituents of granite¹ and pegmatites.² There are only two minerals—thorite and thorianite—in which thorium is the principal ingredient, and varieties of these, called uranothorite and uranothorianite, may contain up to 50 per cent uranium. However, monazite, xenotime, and allanite may contain from 1 to 15 per cent of thorium. Of these, monazite is the only presently known commercial source of thorium. Thorium occurs in many uranium-bearing minerals, particularly in those like euxenite, samarskite, and fergusonite of pegmatitic origin, from traces up to 5 to 10 per cent, and also in uraninite.

Descriptions of the thorium minerals will be found in Chapter VI and in Appendix II. These minerals are also included in the Radioactive Minerals Identification Table in Appendix III.

BERYLLIUM

Beryllium is a rare metal, steel gray in color, and capable of taking a high polish. With an atomic weight of 9 and specific gravity of 1.84, it is much lighter than aluminum or magnesium and is, in fact, the lightest known metal, except for lithium. Beryllium is neither radioactive nor a source material. It does have, however, several important new uses and possibilities in the atomic energy program. In addition to the importance of both beryllium oxide and

¹ Granite is one of the most common of the *igneous* rocks, the primary rocks of the earth's crust which have solidified from a molten state and from which the *sedimentary* and *metamorphic* rocks are derived; it is composed primarily of mica, quartz, and feldspar.

² A pegmatite is a vein-like body with a pod-like or lens shape and with essentially the same composition as granite, but characterized by unusually large crystals of mica, quartz, and feldspar, and unusual concentrations of rare minerals.

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beryllium metal as structural materials or moderators for high-efficiency pile construction, beryllium is an exceptionally attractive material for certain special ceramic, electrical, and metallurgical purposes.

The estimated content of beryllium in the earth's crust is about the same as that of thorium or slightly less. Since beryllium is not radioactive and cannot be detected on the basis of this property, and because the chemical determination of beryllium is difficult and time-consuming, the extent to which beryllium is dispersed throughout the majority of rocks is not so well known. It is probable that beryllium is not dispersed as widely as uranium and thorium. It has been detected in minute amounts (a few thousandths to a few hundredths of a per cent), however, in a variety of mine, mill, and smelter products, particularly flue gases, and in clay, bauxite (an aluminum mineral), and coal in many parts of the United States. Although, or perhaps because, beryllium is apparently less evenly dispersed throughout the rocks of the earth's crust than uranium or thorium, the number of known relatively high-grade commercial deposits is much greater; and, even though it must still be considered a rare element in this respect, its production in terms of high-grade ore prior to the atomic era was considerably larger than that of uranium or thorium. It had been produced for more than sixty years, and annual world production has exceeded 5,000 tons at least twice.

Beryllium has been found in some fifty-six minerals, about one-half of which contain in excess of 1 per cent beryllium. However, of all the beryllium-containing minerals, only one—beryl—has been found in sufficient quantities and in rich enough concentrations to be used commercially. The remaining minerals are either too rare or contain such small amounts of beryllium that they do not lend themselves to known methods of extraction. Descriptions of the more common beryllium minerals will be found in Chapter VIII.



MINERAL AND ORE DEPOSITS

The earth's crust is usually considered to have a thickness of about 10 miles. It has been penetrated by man in mining operations to almost 2 miles and by drilling to nearly 3 miles. The rocks making up the crust are of types that are exposed on all the continents at the surface; igneous rocks, such as granite, rhyolite, or basalt, are formed directly from a molten state. Metamorphic rocks, such as gneiss, schist, or marble, are formed from other rocks by high pressures, temperatures, or chemical processes. Sedimentary rocks, such as sandstones, limestones, and shales, are formed by the redeposition of the constituents of other rocks which have been broken down by weathering and erosion processes.

The rocks of the earth's crust are in turn made up of minerals containing the natural elements, including uranium, thorium, and beryllium. As we have seen, figures have been developed for the average content of these, and most of the other elements in the earth's crust, through analysis of hundreds of rock samples. With the exception of a few of the most common elements, like silicon or calcium, these figures are so low that they are of little significance to the problem of extracting the elements for human use. Fortunately, however, the earth's crust is not at all homogeneous, and there are great variations in the concentrations of the various elements and the minerals that contain them from place to place. These great variations in the rocks and minerals of the earth's crust are caused by the action and reaction of a variety of rock-forming processes in operation since the beginning of time, and when these processes produce an unusual accumulation or concentration of a mineral or minerals at a given spot, the result is a *mineral deposit*. If it is an unusual concentration of uranium minerals, for example, it is called a uranium deposit.

The study of mineral deposits is a science in itself—the science of how and why mineral deposits are formed and, when applied practically, where to look for deposits of a particular mineral. Volumes have been written on this subject, and mining geologists spend years in its study and lifetimes in the pursuit of additional knowledge. Since this is intended to be a practical book on prospecting for atomic energy minerals only, there is space here to summarize only briefly the principles of this science as an aid to understanding the informa-

tion to follow on the occurrence of deposits of those minerals. Persons interested in delving more deeply into this science—and the really serious “atomic prospectors” are encouraged to do so—should refer to the standard textbooks on the subject.

The science of mineral deposits is the study of the geologic processes that lead to the formation of mineral deposits. Waldemar Lindgren, whose book, *Mineral Deposits*, was first published in 1913 and is still the basic work on this subject, called these “processes of concentration,” and they are listed and briefly described below in what might be considered chronological order for a given area of the earth’s crust and a single geologic cycle.¹

1. *Differentiation by fractional crystallization and unmixing in cooling magmas.* As a large body of molten rock beneath the surface of the earth, called a *magma*, cools, different minerals crystallize out at different stages, or liquid components of specific composition will separate, forming segregations of particular minerals or groups of minerals within the magma itself. Certain deposits of iron, titanium, chromium, nickel, copper, diamonds and the precious metals, have been formed in this way.

2. *Salic extracts.* Potassium and sodium (alkali) feldspar and quartz tend to separate out in the upper parts of a magma during cooling and are deposited as pegmatites in the upper edges of the solidifying mass, along with many of the minerals of the rare metals, including some of the uranium, thorium, and beryllium minerals. The only commercial deposits of beryllium are of this origin.

3. *Hot gaseous and liquid solutions escaping from the cooling magma into surrounding rocks.* These are what geologists call *hydrothermal solutions* and are responsible for a large proportion of the mineral deposits containing the useful metals. They are responsible for many of the commercial primary deposits of uranium.

These three processes of concentration—differentiation, salic extracts, and hydrothermal solutions—are responsible for the formation of what are called *primary* minerals and mineral deposits; they are formed first in the geologic cycle and are in their original state of formation and deposition. Subsequently other processes may affect the primary deposits, forming new minerals or new concentrations, or both. These are called *secondary* minerals and mineral deposits and are formed by the following processes of concentration:

1. *Concentration by underground water.* Surface waters are continually moving through the rocks of the upper part of most of the earth’s crust, and they dissolve, move, and redeposit, usually in different forms, various of the minerals with which they come in contact. Deposits of iron, copper, lead, zinc, vanadium, and uranium minerals have been formed in this manner.

¹ Also see Appendix IV.

MINERAL AND ORE DEPOSITS

2. *Concentration by surface waters in the zone of oxidation.* Waters close to the surface often oxidize and decompose the rocks, leaving residual concentrations of only the most difficultly soluble minerals and thus forming mineral deposits. Enrichments of existing mineral deposits may be caused in this way, as is known to be the case in certain copper, lead, zinc, manganese, nickel, and iron deposits. The solutions, as they move downward, may also redeposit dissolved minerals as secondary sulfides of various metals in a process called *supergene enrichment*. This is a particularly important factor in the case of certain copper deposits—the formation of enriched zones of the copper minerals, chalcocite and covellite.

3. *Concentration by sedimentation.* During the process of weathering and erosion of igneous rocks and the formation of sedimentary rocks, sorting of minerals and chemical and biochemical reactions take place that result in the formation of deposits of iron, manganese, phosphorus, and the salts of sodium, boron, and many other elements. Many of these are precipitated in sea or lake waters. Moving and sorting of minerals alone, without chemical action, after rock disintegration, produce placer deposits of precious metals and heavy minerals. This is the major source of monazite, the principal thorium mineral.

4. *Concentration by biochemical processes.* Phosphorus, calcium, silicon, iron, and manganese minerals may be concentrated by animal and bacteria processes. Such deposits may often contain small amounts of copper, zinc, arsenic, iodine, vanadium, and uranium and thorium.

In addition to the division of mineral deposits into primary and secondary deposits, geologists also divide them into two groups according to the time relation between their formation and that of the enclosing rocks in which they are found. *Epigenetic deposits* are those formed after the formation of the surrounding rock by deposition in cracks or veins, by filling of cavities, by filling between the grains or crystals of the *country rock*, or by complete replacement of parts of the enclosing rock formation. The latter type is called a *replacement deposit*. All hydrothermal deposits and pegmatites—that is, all primary deposits except magmatic differentiations—are epigenetic. *Syngenetic deposits* are those formed at the same time and as part of the rock formation in which they are found. Magmatic differentiations and sedimentary and biochemical concentrations are syngenetic deposits.

It is often easy to distinguish between the major types of deposits by their obvious structural characteristics and general appearance, as for instance veins, pegmatites, placers, and the more obvious magmatic differentiation deposits. However, hydrothermal vein deposits are further divided into *hypothermal* (high temperature), *mesothermal* (medium temperature), and *epithermal* (low temperature) deposits on the basis of temperature and pressure of formation,

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generally related to the depth below the surface at which deposition occurred. Since rock erosion, deposition, or both have usually occurred subsequent to formation of the deposit, the relationship of the deposit to the present ground surface is not usually an indication. The geologist or prospector must then rely on the more intricate tools of the science of mineral deposits to reconstruct from the evidence available what the conditions of formation were.

One of these tools, a sub-science in itself, is *rock alteration*. When solutions make their way through the rocks, they have an effect on those rocks which is often very marked. The type of alteration—the alteration minerals formed—is an indication of the original composition, temperature, and pressure of the solutions.

Another tool is *geologic thermometry*. Certain minerals will be deposited from a solution only at a particular temperature and pressure. The minerals found in a vein may therefore indicate the temperature and pressure of formation. For instance, arsenic, antimony and bismuth minerals and calcite, dolomite, barite, and fine-grained quartz are common in epithermal deposits; copper, lead and zinc minerals, and more massive quartz are common in mesothermal deposits; the high temperature minerals in hypothermal deposits are more likely to be oxides, like magnetite or specularite (iron oxides), cassiterite (tin oxide), and topaz, or silicates such as pyroxene, amphibole and tourmaline.

The pressure of formation can often be determined by the size and number of openings in the vein and its regularity. The more regular and tightly filled, the greater the depth and higher the pressure. Irregular, discontinuous, and splintered veins with many openings encrusted with fine-grained, banded mineralization or widely spaced, large crystals indicate shallow, low-pressure deposition. Generally speaking, high temperature goes with high pressure, but this does not have to be so. Replacement deposits can be recognized by the typical hydrothermal characteristics together with deposition outside the limits of veins and other open spaces into the rock itself by replacement of the original constituents of the rock.

At this point, one may ask, "Why is this all so important? Can't one merely hang his Geiger counter on his shoulder and start looking?" There is not a simple and conclusive answer to that, and it is certainly not the intention here to discourage such an approach. Many uranium deposits have been found in that way, and a great many of the major deposits of the other metals have been found with just as direct an approach, and without even the benefit of the counter. However, most experienced prospectors, even those without academic training, accumulate a large practical knowledge of the principles of mineral deposition.

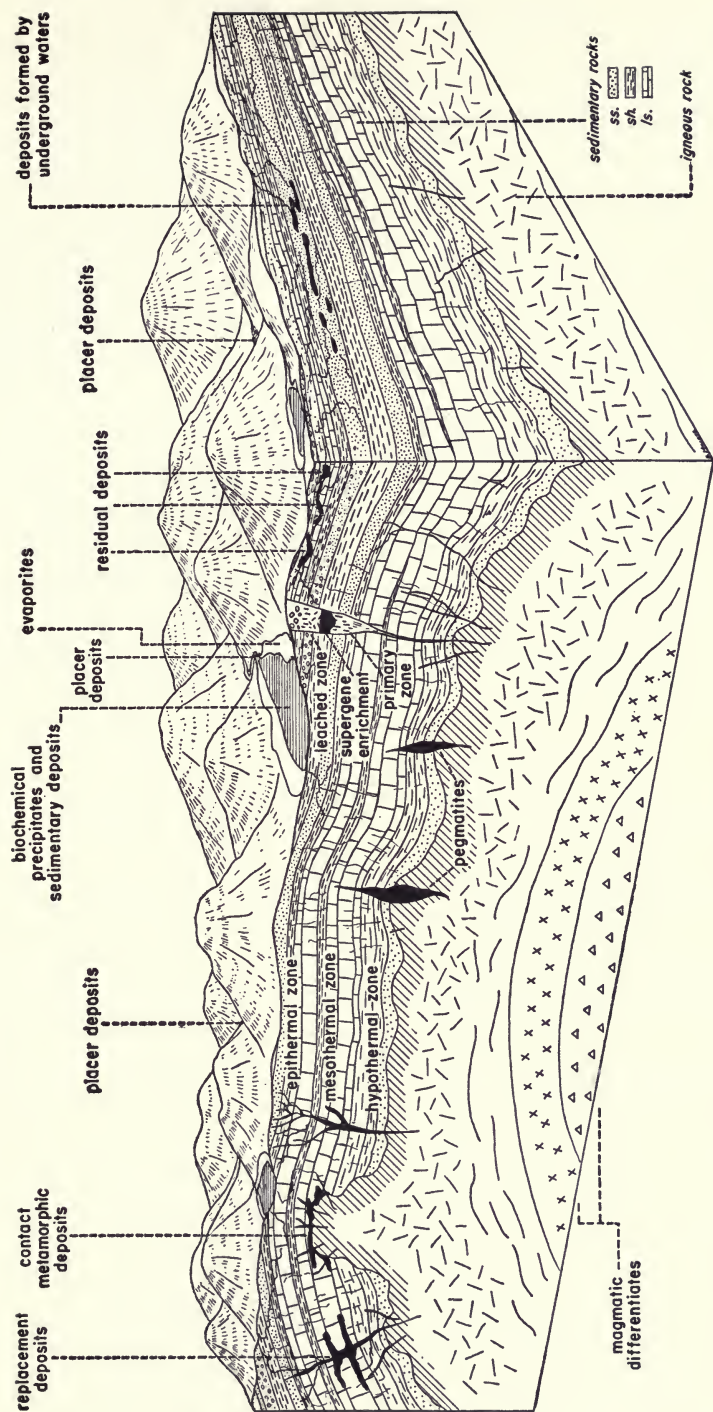


PLATE II. Origin and Formation of Mineral Deposits.

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ORE DEPOSITS

So far, minerals and mineral deposits have been discussed, but little mention has been made of *ore* or *ore deposits*. The reader may well wonder whether there is a difference between a mineral deposit and an ore deposit. All ore deposits are mineral deposits but the reverse is not true.

In a discussion of the characteristics of deposits of atomic energy minerals, how to look for them, how to recognize a valuable one and what to do about it, the question as to whether it is a mineral deposit or an ore deposit may be academic. But the definition has already been given: *valuable*. An ore deposit is a mineral deposit that is valuable—a deposit of a mineral or group of minerals from which a metal or metals can be extracted at a profit.

This definition of ore does two things: it excludes deposits of coal, oil, and other nonmetals which may be considered mineral deposits, and it relates the matter to economics—to the current or prospective market of the metal contained in the deposit. Thus, a mineral deposit that is not an ore deposit today may be one tomorrow because of an increase in the price of the metal, as a result of the development of cheaper mining and metallurgical methods, because of the building of a new road or railroad making the deposit more accessible with respect to the market, or by the market moving closer to the deposit.

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THE URANIUM ORE MINERALS

Lindgren defines an *ore mineral* as "a mineral which may be used for the extraction of one or more metals." A *uranium ore mineral* is therefore a mineral possessing such physical and chemical properties and occurring in a deposit in such concentrations that it may be used for the profitable extraction of uranium, either alone or together with one or more other metals. There are only a few of the many uranium minerals that meet these qualifications and still fewer in which uranium is the major constituent. Pitchblende and uraninite contain theoretically up to 85 per cent uranium but actually between 50 and 80 per cent; carnotite, torbernite, tyuyamunite, autunite, uranophane, and brannerite, 45 to 60 per cent. In other minerals, uranium is an important but relatively minor constituent—the minerals, davidite, samarskite, and euxenite, for example, contain only 1 to 18 per cent. The majority of uranium-bearing minerals, however, contain uranium in small or *trace* amounts as an accessory to other major constituents.

The uranium content of a mineral does not of itself, however, determine whether it is a uranium ore mineral. If the uranium is present in a mineral in such complex combinations with other elements that it is too costly to extract, or if the mineral does not occur in sufficient quantities to make extraction worthwhile, that mineral is not a uranium ore mineral. Thus, the definition for an ore mineral, like that for an ore deposit, is dependent upon economics and time—upon the value of uranium and the results of future exploration and metallurgical progress. A uranium mineral that is not an ore mineral today may be one tomorrow.

Most of the uranium minerals in pegmatites and placers are *refractory*; that is, the uranium is present in combinations which are extremely difficult to break down chemically in order to recover the uranium. These minerals also usually occur scattered sparsely throughout the deposit so that recovery is difficult and expensive. Therefore, even though some of the individual minerals may contain up to 50 per cent uranium, they are not ore minerals.

The fact that only a few of the numerous uranium minerals qualify as uranium ore minerals and form uranium ore deposits, whereas uranium in small amounts is widely spread throughout the rocks of the earth's crust, adds greatly to the problem of uranium exploration. The uranium prospector gets many

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"nibbles" but few "bites," and to avoid disillusionment and frustration, as well as waste of time, effort, and money, he must know his business well. This is one of the most important factors in searching for uranium, as it is for other metals—the ability to judge the importance of what is found and whether to discard it or follow it up. In this respect, it is of first importance to become familiar with the uranium ore minerals.

PRIMARY URANIUM ORE MINERALS

Primary uranium minerals have been found most commonly in veins or pegmatites, although in recent years extensive, flat-lying deposits of pitchblende in sedimentary rocks have also been discovered. The refractory primary uranium minerals are also found in placers.

The primary uranium minerals are generally black or dark brown, noticeably heavy, and often have a shiny or pitch-like luster. When they are exposed to weathering at or near the surface, they are sometimes altered to form the bright-colored secondary uranium minerals. At the present time, there are only three known primary uranium *ore* minerals, and the most important of these, uraninite and pitchblende, are really varieties of the same mineral.

Uraninite (combined UO_2 and UO_3 ; 50-85% U_3O_8).¹ Uraninite is a naturally occurring uranium oxide with cubic or octahedral crystal form. It has a specific gravity of 8-10.5 (iron = 7.85), a grayish-black color sometimes with a greenish cast and a hardness² of 5-6, about the same as steel. Its streak³ is black. Its most widespread occurrence is in pegmatites,⁴ in which it is found in small amounts, throughout the world. However, it is also an important constituent of nearly all important primary deposits, occurring closely associated with its massive variety, pitchblende.

¹ U_3O_8 is the symbol for a chemical compound, uranium oxide, composed of three atoms of uranium to eight atoms of oxygen. Most chemical assays for uranium are expressed in terms of U_3O_8 , and ore purchases are made on that basis. The uranium content equals approximately 85 per cent of the assay expressed in terms of U_3O_8 .

² Hardness of minerals is related to Moh's scale of 1 to 10 using typical minerals as standards:

- (1) Talc: easily scratched by the fingernail.
- (2) Gypsum: scratched with difficulty by the fingernail; will not scratch a copper coin.
- (3) Calcite: same hardness as copper.
- (4) Fluorite: scratches copper; will not scratch glass.
- (5) Apatite: same hardness as glass.
- (6) Feldspar: scratches glass easily; scratched with difficulty by knife blade.
- (7) Quartz: not scratched by knife blade; scratched with difficulty by file.
- (8) Topaz: will scratch quartz.
- (9) Corundum: will scratch topaz.
- (10) Diamond: not scratched by any known substance.

³ Streak: Powder mark left by scratching on a hard surface, such as unglazed porcelain.

⁴ In spite of this typical occurrence, uraninite is not a refractory mineral and should not be confused with the many complex uranium minerals also found in pegmatites.

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Uraninite is the principal uranium-bearing mineral in two newly developed types of deposits that produced for the first time in 1952: the very low-grade (in uranium) Witwatersrand and Orange Free State gold-bearing conglomerates of the Union of South Africa, and the medium-grade uranium and copper-bearing carbonaceous slates at Rum Jungle, Northern Territory, Australia. In both of these deposits uraninite occurs as finely disseminated crystals, usually invisible to the naked eye.

Pitchblende (combined UO_2 and UO_3 ; 50-80% U_3O_8). Pitchblende is the massive variety of uraninite, without apparent crystal form, that occurs most abundantly in the rich primary vein deposits of uranium. It is the chief constituent of nearly all high-grade uranium ores and has provided the largest part of all uranium produced throughout the world, forming the principal product of the Shinkolobwe mine, Belgian Congo; the Eldorado mine, Great Bear Lake, Northwest Territories, Canada; and the mines at Joachimsthal, Czechoslovakia.

Pitchblende is somewhat lighter than uraninite, having a specific gravity of between 6 and 9, but its other properties, with the exception of crystal form, are the same. It occurs as irregular masses often with a rounded, layered, *botryoidal* structure.

The principal occurrences of pitchblende are in primary (hydrothermal) vein deposits, usually of the mesothermal (medium temperature and pressure) type, in igneous and metamorphic rocks and in flat-lying bedded deposits in sedimentary rocks. Pitchblende is commonly associated with one or more of the primary ore minerals of iron, copper, cobalt, lead, silver, and bismuth; and the presence of these minerals in a mineral deposit is one indication of favorable conditions for pitchblende. It is usually accompanied also by bright-colored secondary uranium minerals where subjected to weathering or other alteration. The commonly associated gangue¹ minerals are quartz and other silica minerals, carbonates, fluorite, barite, and hydrocarbons. Quartz, calcite, and dolomite are usually the most abundant. Pitchblende, in vein deposits, is most likely to be deposited in existing open spaces in rock formations, rather than by replacement of the rock itself, and the richest deposits occur where large open fractures were available for filling by the mineralizing solutions. There are no important pitchblende replacement deposits like those of copper, lead, zinc, and silver, where rock formations have been substantially replaced by ore through solution of the original constituents and deposition of the ore minerals.

Deposition of pitchblende is usually accompanied by strong alteration of the wall rock along the veins. The presence of hematite (a red iron oxide mineral) extending from the pitchblende a few inches to a few feet into the wall rock is the most characteristic feature. The formation of hematite has occurred in all

¹ The non-ore minerals in a vein or other ore deposit.

of the major pitchblende vein deposits and in many of the deposits of minor importance. Other alteration features often associated with pitchblende deposition are the formation of kaolin, chlorite, sericite, and silica minerals in the wall rock.¹

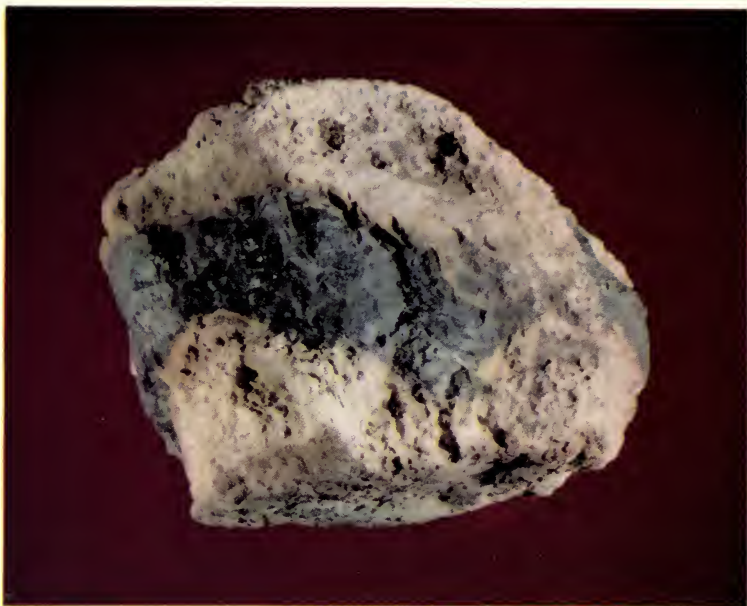
In the recently discovered flat-lying deposits of pitchblende in sedimentary rocks, such as sandstones and conglomerates, the pitchblende is deposited between and around the grains of the rock and in available rock openings. The exact mechanics and chemistry of deposition, however, are not as well understood as they are in the case of the vein deposits. The two most important examples are the "copper-uranium" deposits in southern Utah and northern Arizona, in which pitchblende occurs with a variety of secondary uranium and copper minerals and copper and lead sulfides, and the deposits in Big Indian Wash near La Sal, Utah, in the central Colorado Plateau, where the pitchblende is associated with the vanadium mineral, vanoxite, and some secondary minerals, principally carnotite, tyuyamunite, and becquerelite.

Pitchblende has also been found in smaller amounts disseminated in volcanic rocks in the southwestern United States, in some of the carnotite deposits of the Colorado Plateau, and in the deposits in limestone in the Grants district, New Mexico.

Davidite (rare earth-iron-titanium oxide; 7-10% U_3O_8). Davidite was not considered a significant uranium ore mineral until 1951, when additional exploration at the old Radium Hill mine near Olary, South Australia, an early producer of small quantities of radium, indicated a substantial uranium deposit. After World War II a few tons of davidite were produced from less important deposits near Tete in Mozambique (Portuguese East Africa). Davidite is a dark brown to black mineral with a glassy to submetallic luster. It has about the same hardness as pitchblende (5-6) and is somewhat lighter in weight (specific gravity, 4.5). It occurs most commonly in angular, irregular masses, sometimes with crystal outlines, but never in round, botryoidal shapes like pitchblende. When it is exposed to weathering, a thin yellow-green coating of carnotite or tyuyamunite may form on its surface. This is particularly true at Radium Hill, Australia, and it provides an easy means of tentative identification in the field.

Davidite is deposited in hydrothermal veins, presumably at a higher temperature and pressure than pitchblende. The veins have many of the characteristics of pegmatites. The associated vein minerals are ilmenite, hematite, biotite,

¹ The alteration of the wall rock to form these minerals is known as kaolinization, chloritization, sericitization, and silification. Kaolinization causes the wall rock to become soft and clay-like, so that it may be easily gouged with a knife blade or even the fingernail. Chloritization and sericitization cause the rock to become a waxy or greasy green or gray, sometimes soft and flaky. Silification results in a hard flint-like texture.



Pitchblende With Alteration Products—Shinkolobwe Mine, Belgian Congo
 From *Prospecting for Uranium*, by U. S. Atomic
 Energy Comm. and U. S. Geological Survey, 1951.



Pitchblende—Great Bear Lake, Canada
 From *Prospecting for Uranium*, by U. S. Atomic
 Energy Comm. and U. S. Geological Survey, 1951.

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mica, quartz, calcite, and pink feldspar. The rocks enclosing the veins at Radium Hill are largely gneisses or schists, with chloritic and sericitic alteration near the veins. At Tete, davidite veins are found in more basic¹ rocks like gabbro and anorthosite. Davidite is almost never found as the "pure" mineral, but rather in complex inter-growths with ilmenite which has very similar physical properties and chemical composition.

SECONDARY URANIUM ORE MINERALS

The *secondary uranium minerals* are by far the most spectacular in appearance of the uranium minerals. Instead of the dull black, gray, and brown colors of the primary minerals, they present an array of bright yellow, orange, green, and all of the combinations and in-between shades of those colors. Some of them also have the property of fluorescence under ultraviolet light, resulting in even more brilliant coloration. Rather than being heavy and massive, they occur as earthy or powdery materials or as fine, delicate, needle-like or platy, flake-like crystals. As a group, they are probably more beautiful than the minerals of any other element. This, of course, is an important factor in their recognition in the field, although the inexperienced prospector may often confuse them with other colorful minerals, such as malachite (copper carbonate), limonite (iron hydroxide), and sulfur, to name a few.

The secondary uranium ore minerals have represented only a small proportion of the total world uranium production to date. However, their deposits are more numerous and widespread than those of the primary ore minerals and, as a result of intensive prospecting activity, their importance is steadily increasing. The secondary minerals have two major modes of occurrence:

1. In the weathered or oxidized zones of primary deposits, where they are formed by decomposition of the primary minerals in place.
2. As irregular, flat-lying deposits in sedimentary rocks, primarily sandstones, but also conglomerates, shales, and limestones, formed by precipitation from solutions that may have carried the uranium some distance away from the original source.

The secondary uranium ore minerals also occur frequently along with a large variety of other secondary uranium minerals, mainly the uranium phosphates, carbonates, sulfates, hydrous-oxides and silicates, in what may be considered a third type of secondary mineral deposit. These have been referred to as *oxidized secondary* deposits or simply as *oxidized* deposits. Most of these deposits are

¹ Rocks having a high iron, calcium, and magnesium content, as opposed to *acidic* rocks having a high sodium, potassium, and quartz content and which are the most common wall rocks of uranium vein deposits.

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probably oxidized vein deposits, the complete oxidation of the primary minerals in place making it difficult to prove the original primary character. On the other hand, they may be formed by ground-water solutions that have dissolved uranium from a broad area of slightly mineralized rocks and concentrated it by precipitation in veins and fracture zones. These deposits are numerous throughout arid and semi-arid regions, such as the western and southwestern United States, the west coast of South America, the Mediterranean area, and southern Russia, and, although a few of them have produced ore, they provide most of the troublesome traces or nibbles that often confound uranium prospectors. In some cases they have proved to be the oxidized upper portions of primary deposits from which primary ore has eventually been mined at depth.

The secondary minerals in the weathered zones of primary deposits have at some places contributed significant uranium production, particularly where weathering has been deep, as at Shinkolobwe in the Belgian Congo; at Urgeirica, Portugal; at Marysvale, Utah; and in some of the copper-uranium deposits of the southwestern United States. However, the major significance of such occurrences to the prospector is the indication of the presence of primary mineralization which, at important deposits, produces in the end the preponderance of the uranium. The flat-lying deposits in sedimentary rocks represent the most important occurrence of the secondary minerals, and the most important deposits of this type are the carnotite deposits of the Colorado Plateau area of Colorado, Utah, Arizona, and New Mexico, which have been radium, vanadium, and uranium producers since 1898.

Three-quarters of the more than one hundred uranium minerals are secondary minerals, but of these only six may logically be considered ore minerals. Most of the others, many of them extremely rare, occur primarily as the weathering products in the oxidized zones of primary deposits, but some are found associated with the secondary ore minerals in deposits in sedimentary rocks. Unlike the primary uranium ore minerals, the secondary ore minerals seldom occur singly or only two to a deposit. They usually occur together in groups of several of both the ore and non-ore minerals, although, as in the case of the carnotite deposits, one mineral may be predominant. The dominant colors of the secondary uranium ore minerals are yellow and green, orange being confined primarily to the non-ore minerals.

Carnotite ($K_2O \cdot 2UO_3 \cdot V_2O_5 \cdot nH_2O$; 50-55% U_3O_8). Carnotite, a potassium uranium vanadate, is the most important of the secondary uranium ore minerals, having provided possibly 90 per cent of the uranium production from secondary deposits. It is a lemon-yellow mineral with an earthy luster, a yellow streak, and a specific gravity of about 4. It occurs most commonly in soft, powdery aggregates of finely crystalline material or in thin films or stains on

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rocks or other minerals. Its powdery nature gives the impression of even greater softness than its hardness scale rating of 2-3 would indicate. It can be easily scratched with the fingernail. Carnotite is not fluorescent.¹

The most noted occurrences of carnotite are in the Colorado Plateau area of the United States, where it was first identified in 1898 and has since provided the major domestic uranium production, on the western edge of the Black Hills, South Dakota, and in the Ferghana basin, U.S.S.R. It occurs in sandstones in flat-lying, irregular, partially bedded ore bodies of from a few tons to a few hundred thousands of tons in size. In the higher-grade deposits (more than one-third of 1 per cent U_3O_8), the carnotite is present in sufficient quantity to color the rock a bright yellow; but in poorer deposits, particularly below 0.20 per cent U_3O_8 , it is often difficult to distinguish it from the sandstone itself. Its color is also often masked by iron staining or by the dark-colored vanadium minerals usually associated with it. Most carnotite deposits range in grade from 0.10 per cent to 0.50 per cent U_3O_8 .

Although carnotite is the principal mineral in the carnotite deposits, nearly twenty other secondary uranium minerals are found associated with it. The most common of these is the secondary ore mineral, tyuyamunite, described below. All of the other secondary ore minerals, torbernite, autunite, schroeckingerite, and uranophane, have also been found in carnotite deposits. The other associated secondary minerals are the rare oxides, carbonates, arsenates, vanadates, phosphates and silicates. The most common non-uranium minerals found associated with carnotite are the vanadium minerals, corvusite (hydrous-vanadium oxide), hewettite (calcium vanadium oxide), and roscoelite (vanadium mica—silicate). Minerals of the common metals, such as copper, lead, zinc, and manganese, have also been identified in carnotite deposits, as well as pitchblende and uraninite, but their occurrence in most cases is only of academic interest.

One other important association of carnotite should be mentioned, for it has an important bearing on prospecting for these deposits. An evident general affinity of uranium for certain organic materials, which has had some effect on its deposition in almost all types of deposits, is perhaps most clearly displayed in the carnotite deposits of the Colorado Plateau area. In a large number of these deposits, the carnotite is intimately associated with silicified or carbonized wood (fossil wood), and a variety of coal-like and asphaltic materials, all of which are good indicator substances for carnotite. In the Temple Mountain district, Utah, carnotite occurs in sandstones so impregnated with asphaltic material that the deposits are considered a special type and

¹ Fluorescence: The property of emitting light or glowing during exposure to ultraviolet light.

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called *uraniferous asphaltite deposits*. Elsewhere, fossil wood in the form of logs or accumulations of branches and twigs, locally called trash pockets, is the most common type of associated organic material.

Although occurrences of the type described represent the only ore deposits of carnotite, this mineral is one of the most widespread of the uranium minerals. It is present in varying amounts in nearly all of the other secondary uranium deposits and is the principal mineral in some of the noncommercial oxidized deposits, like those at Jean and Erie near Las Vegas, Nevada, and near San Carlos, Chihuahua, Mexico. Carnotite is found also in small amounts in the oxidized zone of any primary uranium deposit containing even trace amounts of vanadium, for example, the davidite deposits at Tete, Mozambique, and at Radium Hill, South Australia, in the fluorite deposits of the Thomas Range, Utah, and other parts of the southwestern United States, and in places as thin stains and coatings at the outcroppings of the very low-grade, uranium-bearing shale, phosphate, and lignite deposits.

Tyuyamunite ($\text{CaO} \cdot 2\text{UO}_3 \cdot \text{V}_2\text{O}_5 \cdot n\text{H}_2\text{O}$; 48-55% U_3O_8). Tyuyamunite is closely related to carnotite as indicated by the chemical formula, which is the same except that calcium substitutes for the potassium of carnotite. The physical properties of tyuyamunite are the same except for a slightly more greenish color than carnotite and, in some cases, a very weak yellow-green fluorescence not found in carnotite.

Tyuyamunite is found in small amounts in almost any deposit or with any occurrence of carnotite. It is, as one would suspect, more abundant where there is an appreciable amount of calcium, usually in the form of calcite or limestone. Tyuyamunite first obtained importance as an ore mineral because of its occurrence in a deposit in southeastern Turkistan, U.S.S.R., near the town of Tyuya Muyun, for which it was named. It occurs there, and at other localities in the region, associated with other secondary uranium minerals, particularly carnotite and torbernite, in fractures in limestones, dolomites, and shales. It is also an important constituent of the deposits in limestone at Grants, New Mexico, and has been identified in the deposits at Big Indian Wash, Utah.

Torbernite and Meta-torbernite ($\text{CuO} \cdot 2\text{UO}_3 \cdot \text{P}_2\text{O}_5 \cdot n\text{H}_2\text{O}$; 60% U_3O_8). Torbernite and meta-torbernite are hydrous copper uranium phosphates, the only difference between the two being the number of water molecules present; their physical properties are identical. They have a bright emerald color, a pearly luster, hardness of $2-2\frac{1}{2}$ (about the same as the fingernail), and specific gravity of about 3.5 (a little heavier than quartz). They occur in flat, square, translucent crystals which usually fluoresce with a faint green color.

Torbernite and meta-torbernite are the most common of the secondary uranium minerals that are found associated with primary deposits where oxidation has occurred. They are common in nearly all such deposits except pegmatites,

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which usually do not contain the necessary copper to form them. They are most noted for their abundance in the oxidized zones at Shinkolobwe, Joachimsthal, and in the copper-uranium deposits of Utah and Arizona. They have provided a substantial uranium production from the Urgeirica mine and nearby deposits in Portugal and from Marysville, Utah, and they occur in the oxidized zone at Rum Jungle, Northern Territory, Australia. In addition, they occur with the other secondary uranium minerals in the oxidized secondary deposits whenever copper has been present in the depositing solutions or surrounding rocks. They are associated with tyuyamunite in Turkistan and with autunite at Bukhova, Bulgaria, and at Mt. Painter, South Australia. The principal non-uranium minerals associated with torbernite are the clay minerals, limonite, quartz, pyrite, and the copper sulfides and carbonates.

Elsewhere in this book these two minerals will be referred to simply as torbernite, although actually the most common of the two is probably meta-torbernite.

Autunite and Meta-autunite ($\text{CaO} \cdot 2\text{UO}_3 \cdot \text{P}_2\text{O}_5 \cdot n\text{H}_2\text{O}$; 60% U_3O_8). Reference to the chemical formula will show that these two minerals have the same composition as torbernite, with calcium substituting for copper. Because of this similarity, they are commonly found together, the proportion of torbernite being dependent upon the amount of copper available to the uranium-bearing solutions. In some instances, where copper is completely lacking, only autunite or meta-autunite is formed. Like torbernite and meta-torbernite, autunite and meta-autunite are identical in their physical properties, the distinction being made on the basis of the number of water molecules present. Also, as in the case of torbernite, meta-autunite is probably the most common. For simplification, however, they will be referred to as autunite.

The physical properties of autunite are similar to those of torbernite, except for its color, which is predominantly lemon or sulfur-yellow, although occasionally apple-green, and its brilliant yellow to greenish-yellow fluorescence in ultraviolet light. Autunite has a hardness of $2-2\frac{1}{2}$, is slightly heavier than quartz (specific gravity, 3.1), has a colorless to pale yellow or green streak, and occurs in small square, rectangular, or octagonal flat, translucent crystals or as thin coatings or stains on rock or other mineral surfaces. It is seldom found in large masses but rather as small spots scattered throughout the enclosing rocks. A good autunite exposure is a brilliant sight at night under ultraviolet light, and the inexperienced prospector is apt to overestimate the grade of a deposit seen under those conditions.

Autunite is found in varying amounts in almost all deposits of the other secondary uranium minerals. It is an oxidation product of pitchblende and uraninite and most of the other primary minerals, and may also be derived from some other secondary minerals, like gummite and uranophane. As such

it is an important constituent of the oxidized zones at Shinkolobwe and other important primary ore deposits and is a common secondary uranium mineral in most pegmatites. It is present in small amounts in many of the carnotite deposits of the Colorado Plateau area and in larger amounts in the tyuyamunite deposits of Turkistan.

The greatest significance of autunite to the prospector lies in the fact that it is the most common uranium mineral in the oxidized secondary deposits in igneous rocks of arid regions, both those related to primary mineralization and those of unknown origin. It is an important constituent of the oxidized ores at Urgeirica, Portugal, and at Marysvale, Utah, and the most prominent mineral in the White Signal, New Mexico, district, at Mt. Painter, South Australia, and in the numerous low-grade secondary occurrences in the Mojave Desert and at other localities in southern California and Nevada. In addition, it frequently occurs as thin stains on fracture surfaces in granite and pegmatites in the Appalachian region of the eastern United States from Stone Mountain in Georgia to New England. The associated non-uranium minerals are the same as for torbernite, except that the copper minerals may be absent.

Uranophane ($\text{CaO} \cdot 2\text{UO}_3 \cdot 2\text{SiO}_2 \cdot 6\text{H}_2\text{O}$; 65% U_3O_8). Uranophane is a hydrated calcium uranium silicate containing silica in place of the phosphate of autunite. It is slightly lighter in color and somewhat heavier than autunite (specific gravity, 3.85) and has a different crystalline form; it may occur as stains or coatings without apparent crystal form or as finely fibrous or radiating crystal aggregates.

The origin and occurrence of uranophane are very similar to autunite and torbernite. At least two of these three minerals are almost always found together, in proportions varying with availability of copper and phosphorus, uranophane becoming predominant where these two elements are scarce or absent. Although it has as broad a geographic occurrence as the other two, uranophane, with a few exceptions, is usually present in smaller quantities. It is an important constituent of the secondary deposits in limestone near Grants, New Mexico, where it earned its reputation as an ore mineral, and in recently discovered deposits in sandstone in southern Carbon County, Wyoming. It is also the most common secondary uranium mineral found in the non-commercial deposits in granite and pegmatites in the eastern United States. Its most noted occurrences of this type are at Stone Mountain, Georgia (granite), and at the Ruggles mine at Grafton, New Hampshire (pegmatite).

Schroeckingerite [$\text{NaCa}_3(\text{UO}_2)(\text{CO}_3)_3(\text{SO}_4)\text{F} \cdot 10\text{H}_2\text{O}$; 30% U_3O_8]. Schroeckingerite is a complex hydrated sulfate, carbonate, and fluoride of calcium, sodium, and uranium. It has a yellow to greenish-yellow color with a pearly luster, a bright yellow-green fluorescence, and a paler yellow or greenish-

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yellow streak. It is very soft (less than 1 on the hardness scale),¹ easily water soluble, and is the lightest of the uranium minerals (specific gravity, 2.5). It occurs as globular coatings on rock fracture surfaces or as small rounded masses composed of aggregates of flaky crystals distributed through soft rocks or soil.

Schroëckingerite is the least important of the uranium ore minerals and barely qualifies as such. It is a significant constituent of the secondary ores at Marysvale, Utah, and probably occurs in small amounts in the oxidized zones of most of the important primary deposits. The only known occurrence in which schroëckingerite is the principal mineral is at Lost Creek near Wamsutter, Wyoming. It occurs there as small pellets distributed through clay beds at or near the ground surface over a considerable area to form a low-grade uranium deposit that is presently submarginal. In this type of deposit there are no significant associated minerals.

¹ Apparent hardness—theoretical hardness 2.5.

IV

THE OTHER URANIUM MINERALS

A considerable number of the many uranium minerals other than the ore minerals deserve specific, but brief, attention. These are the minerals that occur frequently in association with the uranium ore minerals, or are found in deposits by themselves but in insufficient quantities to make ore. They may be leads to ore deposits, or they may be misleading and result in an unnecessary waste of valuable time and effort. Some of these minerals will undoubtedly eventually be found in commercial concentrations and will graduate to the ranks of the ore minerals. In some cases it is very likely that they will do so by way of the *by-product* route. That is, methods may be devised to separate and sell profitably relatively small quantities of these uranium minerals mined in conjunction with the mining of other minerals.

The other uranium minerals may be divided into two groups:¹

1. Secondary minerals of a variety of occurrences.
2. Refractory primary minerals in pegmatites, granite and placers.

It is the latter group that presents the possibility of by-product value.

SECONDARY MINERALS

These minerals are of primary interest to the scientifically minded prospector, the mineral collector, and the student. They are not likely to provide in themselves leads to uranium ore deposits, because they are nearly always intimately mixed with the more easily recognized primary or secondary uranium ore minerals.

REFRACTORY PRIMARY MINERALS

Pegmatites. Most of the primary uranium minerals, other than the three ore minerals, were deposited originally in pegmatites or granite. Pegmatites are very common throughout the world, and some primary uranium minerals are likely to be found in most of them. Since pegmatites are also the principal commercial sources of such minerals as beryl, columbite, tantalite, lepidolite and spodumene (lithium ore minerals), mica, and feldspar, there is always the possibility that uranium minerals will one day be found in sufficient

¹ Descriptions of the individual minerals will be found in Appendix I.

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quantity under conditions that will permit profitable recovery as a by-product.

Granite. All granites have an excess of radioactivity that can be detected in the field over that of most other rocks; the background count of a field counter will usually be higher over granite than over sandstone, limestone, or shale. This radioactivity is usually due primarily to the potassium contained in feldspar in the granite and to thorium minerals which are normally present in all granitic or pegmatitic rocks. However, many of the primary uranium minerals occur in granite, as well as in pegmatites. Some granites contain enough of these minerals to provide an average uranium content equivalent to that of uranium-bearing phosphate, shale, or lignite. Granites containing an unusual abundance of the primary uranium mineral, pyrochlore, are known in Nigeria and in the United States. Such deposits may eventually be mined for columbium, which they usually also contain, and provide a by-product source of uranium.

Alluvial or Placer Minerals. The rocks at the earth's surface are continuously subjected to the chemical and mechanical processes of weathering and erosion. These processes break down the rocks, releasing the component minerals which may be carried away by water or wind action and redeposited elsewhere. The less-resistant minerals are carried away in solution; but the resistant or refractory minerals, freed from the rest of the original rock, are transported by streams and rivers varying distances from their source rock, depending upon their size, weight, and resistance to decomposition. When these minerals are finally redeposited by the streams and rivers they are called *alluvial deposits*, and if they contain valuable minerals they are *placer deposits*.

Since only the most resistant minerals can escape decomposition long enough to be moved and redeposited in a placer deposit, none of the secondary uranium minerals, which are all easily soluble, would be expected there except as occasional surface oxidation coatings on the primary minerals. Pitchblende and uraninite are only slightly more resistant and are found only occasionally in very small quantities near the source rock.

Most of the refractory primary uranium minerals have been identified in placer deposits, and some of them are more noted for their occurrence in placers than in pegmatites. Microlite occurs in tin placers in western Australia; and euxenite, brannerite, fergusonite, and, to a lesser extent, samarskite are found in the gold-monazite placers of central Idaho and Korea and in the tin placers of Thailand and Malaya. Brannerite was first described from a gold placer in Kelley Gulch, Custer County, Idaho. Only thucholite and betafite are not known in placer deposits. However, even the relatively refractory primary uranium minerals are less resistant to disintegration and decomposition than the precious metals and the thorium, tin, titanium, and zirconium

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minerals, all of which occur in commercial concentrations in placer deposits. As a result, the uranium minerals, when present, occur nearer the original source rock in the coarser gravel deposits of stream beds, rather than in the fine-grained sand deposits along beaches and major rivers.

Typical placer deposits of uranium minerals have not been commercial sources of uranium. It is not unlikely that it will be recovered in the near future, however, as the demand for columbium, which is present in most of the uranium placer minerals, increases and stimulates production from new sources. Placers also provide the opportunity for uranium recovery as a by-product of the production of precious metals, monazite, ilmenite, magnetite, zircon, cassiterite, and rutile (titanium oxide). Columbite and tantalite are commercially produced from placer deposits, but the uranium content of these minerals is so low, relative to the limited quantity available, and the minerals are so difficult to process, that uranium has so far not been recovered from this source.

A discussion of uranium-bearing placer minerals would not be complete without a brief reference to the gold ores of the Witwatersrand, Pretoria, and of the Orange Free State, in the Union of South Africa, which contain a small but fairly consistent percentage of uraninite. Although the origin of these deposits has been in dispute for many years, many geologists believe them to have been ancient placer deposits. They are now consolidated into rock formations, locally called reefs. If these are truly placer deposits, they represent the first placer uranium production¹ and far exceed in importance anything that might be expected from other placers. These deposits are also unusual, assuming they are of placer origin, in that the uranium mineral is uraninite, which is less resistant than the refractory pegmatite minerals and would not normally be expected in such deposits. Similar uranium-bearing conglomerates were discovered at Blind River, Ontario, in 1953.

Nearly all of the thorium minerals are also refractory and are more commonly encountered in placers than the uranium minerals, and all of them contain some uranium. The thorium minerals are, therefore, a possible by-product source of uranium, but they will be discussed in a separate chapter.

OTHER URANIUM MINERALIZATION

Uranium also occurs in a variety of very large, low-grade sedimentary formations, particularly phosphate rock, shale, and lignite. Such occurrences will not be of interest to the average prospector from the standpoint of possible financial gain, since the uranium content of the rocks is extremely small and production of uranium is possible now only as a by-product of a large established opera-

¹ The first uranium production from these deposits was in November 1952.

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tion for other valuable materials, as in the case of the phosphate rock deposits.¹ However, they represent important potential reserves of uranium, and it is important that the prospector know something of this type of occurrence so that he can recognize and report a new discovery to the Atomic Energy Commission. Should he discover a deposit of slightly higher uranium content than those now known, with the corresponding lower cost of uranium recovery, it could be of extreme importance.

The manner of occurrence of uranium in these deposits is only partly understood. It does not usually occur in distinct minerals that can be recognized by the eye, or, in most cases, even under the microscope. The principal method of field identification available to the prospector is the measurement of the radioactivity with a Geiger or scintillation counter. But even this is hard because the uranium content is usually less than one-half pound per ton (0.025%) and often less than one-fifth pound per ton (0.01%), and it is difficult to distinguish such a deposit from many other rock formations that also have appreciable radioactivity. Only occasionally do such deposits have telltale films of one or more of the secondary uranium minerals on the exposed surfaces or in cavities and crevices of an outcrop.

Phosphate Rock or Phosphorites. Phosphorites occur in broad, continuous beds from a few feet to 30 or 40 feet thick. They are often composed of small nodules of sand size or slightly larger, as in the pebble phosphate formations of Florida, which are light in color—pale green, gray, yellow, or stained orange or brown where surface leaching has occurred—or they may be dark-colored, massive beds like those of Idaho, Wyoming, Utah, and Montana. The uranium is believed to be present in the mineral apatite or fluorapatite (calcium phosphate with minor carbonate and fluorine). Action by ground waters may result in an increase in uranium content and in the occasional formation of autunite. Occasional carnotite stains may also be formed in those phosphate rocks that contain both uranium and vanadium. Phosphate rock often fluoresces, and there is some evidence that the fluorescence increases with increased uranium content.

Bituminous Shales. Bituminous shales are more common than phosphate deposits, but, unlike the latter, only a few of these shale deposits are considered at present to be potential sources of uranium. Most uranium-bearing shale deposits contain less uranium than the average phosphate deposits.

Bituminous shale deposits, like phosphate rock, occur as broad, continuous formations. They are nearly jet-black in color, and the uranium-bearing portions are likely to be relatively thin, from 2 or 3 to 15 feet at most. The best-

¹ Several million tons of phosphate rock are mined yearly in the United States for fertilizer. The first commercial uranium was produced as a by-product of this industry in 1952.

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known uranium-bearing shale in the United States is the Chattanooga shale of east-central Tennessee and southern Kentucky. It is composed of about one-third fine-grained quartz, one-third clay minerals and mica, and one-third organic matter (including petroleum), pyrite, calcite, phosphate, and aluminum minerals, as well as traces of a large number of other minor elements. The uranium is believed to be associated with the clay minerals.

Portions of the alum shale beds of southern Sweden have a higher uranium content than the Chattanooga shale. Much of the uranium occurs in nodules of a black hydrocarbon called *kölm*, resembling in some respects the uranium mineral thucholite. Kölm may contain up to 0.5 per cent U_3O_8 .

Experimental production of uranium from shale is reported only from Sweden. Important production from shale will probably depend upon the development of processing methods that will permit the extraction of several of the other materials present, such as petroleum and aluminum. Shale of high petroleum content, such as the Rifle, Colorado, oil shale, does not have detectable uranium.

Lignite and Coal. Lignite is the lowest rank of coal and has lower heating value than bituminous or anthracite coal. It has the same origin and manner of occurrence as other ranks of coal. Lignite is similar in general appearance to other coals, but is brown to gray in color and contains noticeable plant matter. Uranium occurs in certain parts of some lignite deposits in the United States, particularly those in Montana, Wyoming, North and South Dakota, Idaho, and New Mexico. The uranium is not as evenly distributed in the lignite as in phosphate rock and shale and usually occurs in thin beds separated by non-uraniferous lignite or other sedimentary beds. It is also unevenly distributed through the favorable bed, often localized near joints and fractures. The uranium is not visible except as occasional stains formed by secondary minerals. Secondary uranium minerals are also occasionally associated with coals, such as those of the Old Leyden coal mine near Golden, Colorado.

Asphaltites. Traces of uranium have been reported from certain bedded asphaltite deposits such as those in Argentina and the vanadium-bearing asphaltite beds of Peru. However, the uranium content appears to be even lower than in bituminous shale and less consistent. The asphalt lakes, such as those in Trinidad and at La Brea, California, and the vein-like deposits of the gilsonite type, such as those in Utah, West Virginia, and Nova Scotia, do not contain uranium.

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Producing uranium deposits and important deposits of potential production may be divided into two major groupings: (1) deposits of obvious hydrothermal origin usually in acidic or granite-like igneous rocks or in metamorphic rocks of high silica content; (2) flat-lying deposits in sedimentary rocks.

The first category includes the pegmatites and the vein deposits of which only the latter, and primarily those formed under conditions of moderate temperature and pressure (mesothermal deposits), have provided important production. The flat-lying deposits include the following:

1. Deposits of principally secondary minerals in sandstones of the Colorado Plateau carnotite type; probably of secondary origin, but introduced into the host rock after its formation.

2. Deposits of principally secondary minerals in limestones and asphaltic sandstones; similar in type and origin to those in sandstones.

3. Deposits of principally uraninite or pitchblende in sandstones; origin uncertain.

4. Deposits of both primary and secondary minerals of the copper-uranium type in conglomerates and sandstones introduced into the host rock after its formation but of uncertain origin.

5. Deposits of uranium phosphates and arsenates in sandstones.

6. Deposits of secondary origin in phosphorites formed at the time of formation of the host rock.

7. Deposits of similar type and origin in bituminous black shales.

8. Deposits of obscure origin in lignites and coals.

Examples of two additional types of deposits that do not fit into the two major categories will also be described:

1. *Oxidized secondary deposits* that have not proved to be merely the oxidized portions of hydrothermal vein deposits.

2. *Placer deposits.* The Witwatersrand and Orange Free State gold deposits are the only uranium-producing deposits that might qualify under this category, but their origin is in dispute. Eventual uranium production from obvious placer

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deposits will probably be a by-product of thorium or columbium production from deposits described in Chapter VII.

PRIMARY VEIN DEPOSITS IN IGNEOUS AND METAMORPHIC ROCKS

Of the great variety of uranium occurrences in the world, the primary vein deposits of uraninite or pitchblende have been the most productive. Although relatively few in number, they have produced by far the largest share of the world's uranium supply to date, and most of this production has come from the deposits at Shinkolobwe in the Belgian Congo, at Joachimsthal in Bohemia and adjacent areas in Saxony, and at Port Radium, Northwest Territories, Canada.

Shinkolobwe Mine, Belgian Congo. The Shinkolobwe mine has been, since its initial development in 1921, the richest known uranium deposit and the greatest single source of uranium. It has probably produced more uranium than all other deposits together. It is located near the town of Jadotville in Katanga in the extreme southern part of the Congo near the border of Northern Rhodesia, about 80 miles northwest of Elizabethville and about 11° south of the equator. The area is typical of the central African savannah country; low rolling hills dotted with clumps of subtropical trees and covered with thick soil and tall grass providing few rock outcrops.

The presence of copper mineralization in the area had been known by the natives for many years, but the existence of uranium was first recognized in 1915 during exploration for copper by Europeans along the outcrops of the rocks in which the Shinkolobwe ore bodies occur. At the most westerly of these outcrops, which were spectacularly colored by the bright green, yellow, and orange secondary minerals formed by the deep tropical weathering, a ridge, formed by the more resistant silicified and mineralized rocks, rose some 35 feet above the surrounding countryside. In a shallow trench just below the soil cover at that point, a large body of pitchblende was found. Further trenching later revealed a network of crisscrossing fractures in the rock filled with pitchblende and the bright-colored secondary uranium minerals.

The ore-bearing rocks at Shinkolobwe are a very old (pre-Cambrian¹) series

¹ A general term used for the oldest rocks in the *geologic time scale*, summarized below:

| | <i>Approximate Age of Beginning of Period in Millions of Years</i> |
|-----------------------------|--|
| <i>Cenozoic or Tertiary</i> | |
| Recent..... | ... |
| Pleistocene..... | 1 |
| Pliocene..... | 10 |
| Miocene..... | 30 |
| Oligocene..... | 40 |
| Eocene..... | 60 |
| <i>Mesozoic</i> | |
| Cretaceous..... | 130 |
| Jurassic..... | 155 |
| Triassic..... | 185 |

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of metamorphic beds called locally the "Mines Series," comprising dolomites (magnesium carbonate rock, similar to limestone), dolomitic shales, and quartzites. These rock formations have been compressed into a series of tight folds, resulting in great breaks or faults where, in some cases, older rocks were thrust up over younger ones. The Shinkolobwe mine is located in one of these complex fault *overthrusts*. A major fault zone cuts across the mine, intersecting the Mines Series and causing numerous smaller cross fractures. The major ore bodies are located where these cross fractures intersect certain favorable beds of the Mines Series—a thin-bedded quartzite and a dolomitic shale—and in closely connected, broken or "brecciated" areas of these rocks.

The veins thus formed pinch and swell, varying in width from a few inches to several feet, and no one of them can usually be traced for more than a few feet. The veins in some places are almost pure pitchblende and in other places are made up primarily of cobalt and copper sulfide minerals with minor pitchblende. The open fissures and zones of crushed rock were favored by the richer uranium-bearing solutions. On the other hand, the other metals were often deposited in much smaller spaces in less broken rock in the walls of the veins. In addition to pitchblende and cobalt minerals, the Shinkolobwe ores carry significant quantities of copper, molybdenum, iron sulfides, tungsten, gold, platinum, and palladium.

The weathering of the ore bodies has extended several hundred feet in depth. Near the surface there are a host of the bright-colored secondary uranium minerals, including becquerelite, curite, uranophane, autunite, and torbernite. The torbernite accounts for more than half of the uranium in the oxidized zones of the ore bodies and is often spread throughout the surrounding rocks. A typically weathered vein will have a central core of pitchblende surrounded by successive zones of yellow, orange, and green secondary minerals.

Joachimsthal Region, Czechoslovakia and Germany. Silver mining was carried on extensively in the early sixteenth century at Joachimsthal in western Czechoslovakia near the German border about 30 miles northeast of Karlsbad.

| | <i>Approximate Age of Beginning of Period in Millions of Years</i> |
|----------------------------|--|
| <i>Paleozoic</i> | |
| Permian..... | 210 |
| Pennsylvanian..... | 230 |
| Mississippian..... | 265 |
| Devonian..... | 320 |
| Silurian..... | 360 |
| Ordovician..... | 440 |
| Cambrian..... | 520 |
| <i>Pre-Cambrian</i> | |
| Proterozoic..... | 1,000 (?) |
| Archeozoic or Archean..... | ? |



Torbernite—Shinkolobwe Mine, Belgian Congo
From *Prospecting for Uranium*, by U. S. Atomic
Energy Comm. and U. S. Geological Survey, 1951.



Carnotite—Colorado Plateau
From *Prospecting for Uranium*, by U. S. Atomic
Energy Comm. and U. S. Geological Survey, 1951.



PLATE III. Open-pit, Shinkolobwe Mine, Belgian Congo. Courtesy Union Minière du Haut Katanga.

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The ore outcrops were particularly rich in both silver and cobalt, and in the middle of the nineteenth century it was discovered that the ore also contained pitchblende, which then had a commercial demand as a ceramic coloring agent. The mines at Joachimsthal had a world monopoly in radium for a short period after its discovery in 1898 until the discovery of the rich carnotite logs which provided the early production from the Colorado Plateau area in the United States.

The Joachimsthal deposits and the adjacent deposits in Saxony are in a heavily wooded, mountainous region called the Erz Gebirge. The favorable host rocks at Joachimsthal are a series of pre-Cambrian schists and slates which have been intruded by granites. The veins in these rocks are in two groups at approximately right angles to each other. Silver, cobalt, nickel, bismuth minerals, and pitchblende, are deposited in the veins, together with quartz, calcite, and dolomite. The veins range in width from a fraction of an inch to 40 inches and average 6 to 24 inches. They follow long fractures that have been traced for thousands of feet along the surface. Pitchblende occurs in thin banded, fairly continuous seams in veins of dolomite and quartz, alone or with the other metallic minerals. It also occurs to some extent in streaks and isolated patches in the veins or within sheared zones in the wall rock.

Silver ore is most abundant in the upper workings; cobalt, nickel, and bismuth minerals predominate in the middle levels of the mines, and pitchblende mineralization is most abundant in the lower workings. The richest pitchblende concentrations are located where the veins cross limestone interbedded with schist. Where the veins pass into granite, mineralization is generally absent. Uranium is found at the surface in many localities in Saxony, just across the border in Germany, and the outcrops of these shallow surface deposits are usually colored by the green and yellow of torbernite and autunite.

Eldorado Mine, Port Radium, Northwest Territories, Canada. A third important pitchblende vein deposit, and one which until recently represented the second largest source of supply of uranium to the United States, is the Eldorado Mine at LaBine Point on Great Bear Lake in Canada, just south of the Arctic Circle, in an area of low-lying but rugged granite hills. A Canadian Geological Survey party in 1900 first noticed that the cliffs on the east side of McTavish Bay were stained pink and green from cobalt and copper minerals. In 1930 Mr. Gilbert LaBine discovered silver and cobalt on a small island a short distance offshore from the present location of the Eldorado mine. Later, veins containing pitchblende, silver, cobalt, and nickel minerals, which later became the Eldorado mine, were found on the mainland.

Mr. LaBine's discovery stimulated additional prospecting for pitchblende in the area because of its value as an ore of radium, and many additional veins were found in the vicinity of the Eldorado mine, to the south along the western

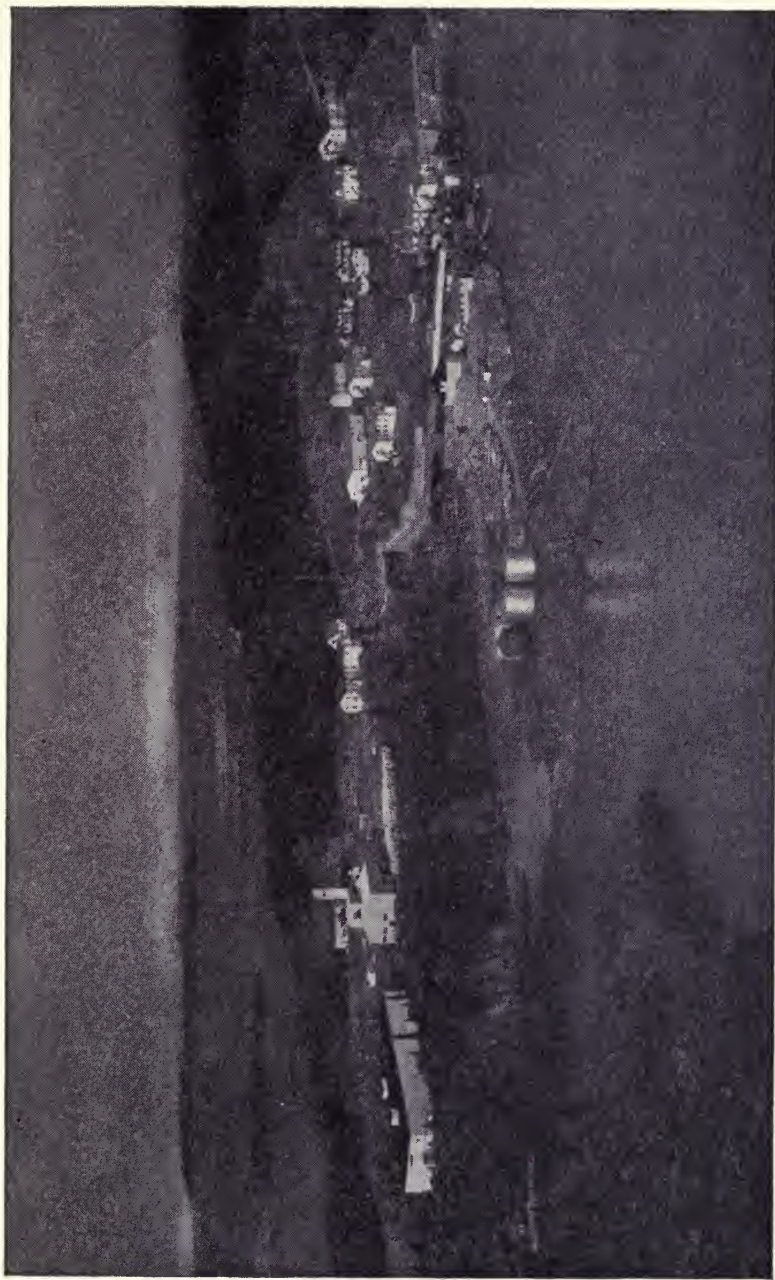


PLATE IV. View of Eldorado Mine, Port Radium, Great Bear Lake, Canada. Photograph by George Hunter. *Courtesy Eldorado Mining and Refining Ltd.*

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edge of the Canadian Shield at Contact Lake, Beaver Lodge Lake, and Hottah Lake, and as far south as Lake Athabaska. However, until 1953, the veins at Eldorado were the only important producers of uranium.

The rocks at Port Radium, like those at Shinkolobwe and Joachimsthal, are pre-Cambrian in age. They consist of metamorphic rocks that were originally sediments and volcanic tuffs (ash deposits), intruded by masses of granite and in places stained heavily with the red color of hematite. The rocks in the vicinity of the mine are folded into a basin-like structure (syncline). The outcrops of the veins usually occupy the bottoms of long shallow valleys carved by the advancing ice of the Pleistocene period of glaciation along the weaker, fractured zones which the veins had filled. Pitchblende and silver, copper, cobalt, and nickel minerals are found at or near the surface in the larger veins, whose outcrops are conspicuous by the presence of the green, orange, and yellow secondary uranium minerals, pink cobalt "bloom," and green copper minerals. A concentration of native silver occurs in the upper mine workings, as at Joachimsthal.

The four most productive veins, which are some 500 to 600 feet apart, appear to converge toward the north; a fifth vein is to the north of the principal vein system. All of the veins occupy fracture zones that can be traced for several thousand feet along the surface. The veins vary in width from a few inches to 15 feet, and one ore body comprising a network of intersecting fractures was mined up to a width of 40 feet. The ore bodies range in length from 500 feet to 700 feet and are known to extend to more than 600 feet in depth. The best ore is found where fracturing is most prominent, usually in the fine-grained metamorphic rocks. Only minor ore occurs in the granite.

Among more than 40 different metallic minerals identified, pitchblende, chalcopyrite, argentite, galena, pyrite, native silver, bismuth, and cobalt-nickel minerals are the most common. The cobalt-nickel mineralization predominates and is found in nearly all of the ore bodies. Pitchblende may occur in solid masses up to a foot in width or as lenses only a few inches wide or as disseminations in the vein filling. The gangue minerals are quartz, carbonate, and hematite, and minor amounts of chlorite, barite, and fluorite.

Beaverlodge Area, Saskatchewan, Canada. The Beaverlodge area of Saskatchewan is a region of numerous pitchblende or uraninite-bearing veins or groups of veins, as well as large, horizontal or gently inclined mineralized zones that achieved production first in 1953 and represents one of the two or three most important postwar uranium developments. In addition to uranium, this region has deposits of gold, copper, lead, zinc, and iron. The principal uranium area extends from 25 to 30 miles on either side, and about 25 miles to the north, of the town of Goldfields on the north shore of Lake Athabaska near the border of Saskatchewan and the Northwest Territories. It comprises a rugged

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subarctic terrain of low-lying, moss-covered, rocky hills dotted with thousands of lakes. Forests of evergreens and poplars grow in the valleys between the hills and, where sufficient soil is available, along the slopes and crests. The most highly developed part of this area is in the vicinity of Beaverlodge Lake, about 5 miles north of Goldfields, where a large number of deposits have been discovered and several are being brought into production.

The Beaverlodge area is located along the western edge of a very old geologic province of pre-Cambrian rocks known as the Canadian Shield and consisting of highly metamorphosed sedimentary and volcanic beds, granite, and related rocks. The rocks of the area have been extensively folded and faulted. Most of the faults trend in a northeasterly direction and many of the major ones can be recognized by the long, low valleys carved out along their length by the advancing ice during the ice age. The three most prominent faults in the area are the Black Bay, St. Mary's, and St. Louis faults, which have been traced for many miles.

The important uranium deposits are veins, lenses, pods, and vein systems, and flat-lying zones of disseminated mineralization. The vein deposits are mineable only when they occur in the larger veins or when a large number of smaller veins are spaced closely together. Recent developments indicate that the major production will come from the large disseminated deposits.

The most prevalent type of mineralization is a simple one containing primarily pitchblende; hematite, carbonates, quartz, and chlorite as accessory minerals; and only insignificant amounts of other metallic minerals. Some of the best known deposits of this type are the Gunnar Lake deposit of Gunnar Mines, Ltd., near the Saint Mary's Channel, Lake Athabaska, and the Ace, Fay, Ura, Radiore, and Bolger groups of claims of Eldorado Mining and Refining, Ltd., along the St. Louis fault at the north end of Beaverlodge Lake. In many cases the pitchblende at these properties is so finely divided in the rock that it cannot be seen by the naked eye and is detectable only by sampling and assaying or by Geiger or scintillation counter. Sometime, however, veinlets up to an inch in width or highly mineralized zones easily recognized are found. The Bolger claims are notable for the spectacular display of gummite, torbernite, autunite, and other secondary minerals at the surface, unusual in the Beaverlodge area.

A more complex type of pitchblende mineralization also occurs in the area, and is best represented by the Nicholson property south of Beaverlodge Lake. In these deposits the pitchblende occurs with cobalt-nickel arsenides, gold, and some platinum. To date, however, such deposits have not represented important reserves. A distinctive feature of nearly all of the deposits of the area is the bright red hematite staining of the wall rock that accompanies the pitchblende.

The occurrence of uranium in the Beaverlodge area differs in several impor-

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tant respects from the occurrences at Shinkolobwe, Joachimsthal, and Great Bear Lake: (1) Uranium mineralization is spread over a wide area in a large number of deposits rather than being restricted primarily to one location; (2) the deposits are generally of lower grade and do not contain rich concentrations; (3) most of the deposits are simpler mineralogically, containing no valuable by-products; and (4) most of the deposits do not have extensive outcroppings of the bright secondary minerals.



PLATE V. Fay Shaft, Plant and Concentrator, Beaverlodge, Canada. *Courtesy Eldorado Mining and Refining Ltd.*

Devon and Cornwall, England. The mining region of Devon and Cornwall in the extreme southwest of England is one of the oldest areas of mining activity in the world and has been a source of tin and copper for many centuries. Underground mining of tin, copper, and lead was an important industry as early as about A.D. 1450 and continued until the twentieth century. Secondary uranium minerals, principally torbernite, and occasional specimens of pitchblende have been found in perhaps a hundred or more places within this district, which is geologically similar to the Erz Gebirge region of Saxony and

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Czechoslovakia. Three mines in the region, the King's Wood mine, Buckfastleigh, Devon, and the South Terras and Wheal Trenwith mines, Cornwall, have produced pitchblende. The South Terras mine produced a few thousand tons of medium-grade pitchblende ore during the period of 1878 to 1909, prior to the discovery of the Shinkolobwe and Eldorado mines, and ranked as the third most important pitchblende producer, after Joachimsthal and Urgeirica, Portugal.

The pitchblende occurs with quartz in well-developed veins from a few inches to a few feet wide in moderately old slate and slate-like formations. The veins are usually within a mile or less of granite masses which had intruded the slate probably at about the same time that the mineralization occurred. The pitchblende has been oxidized to torbernite, autunite, and other secondary minerals near the surface and to depths of as much as 100 feet. These minerals are not confined to the original pitchblende veins, but have been scattered widely through the rocks by surface waters. The best uranium mineralization is found in the copper mines of the area where mineralization is believed to have occurred at moderate temperatures and pressures rather than with the tin, which is generally considered to be deposited at high temperatures and pressures and which occurs nearer the intruding granite. The copper minerals, chalcocite, chalcopyrite, and bornite, as well as sphalerite (zinc sulfide), galena, and pyrite, are found with the pitchblende and quartz. Gangue minerals other than quartz are fluorite, barite, and calcite and other carbonates.

Front Range, Rocky Mountains, Colorado. The only production of pitchblende in the United States prior to 1949 came from the Central City gold-silver mining district just east of the Continental Divide and about 35 miles west of Denver, Colorado. Several hundred tons of relatively high-grade pitchblende ore were produced during about the same period as that of the production from Cornwall. The production came from gold- and silver-bearing veins in four mines located on Quartz Hill just south of Central City: the Kirk, German-Belcher, Wood, and Calhoun. Since 1945 small amounts of pitchblende have been found in a number of other mines in a continually expanding favorable area. These include the Caribou mine at Nederland, the Copper King mine at Prairie Divide west of Fort Collins, the Smuggler mine near Aspen, and several mines in the Lawson and Ralston Creek districts near Idaho Springs. The Copper King mine provided the first new production from the Front Range area in 1952, followed by the Ralston Creek mine in 1953.

The pitchblende in the Colorado Front Range occurs in small, irregularly distributed nodulés, pods, and veinlets or stringers in large continuous gold-silver-quartz and lead-silver veins in folded pre-Cambrian gneiss and schist.¹

¹ Usually banded, gray-colored, metamorphic rocks, probably derived from sandstones or shales, or, in the case of gneiss, from granite.

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Some of the veins have been traced for as much as one-half mile and mined to a depth of 2,000 feet for their gold and silver and occasionally lead. The principal vein minerals, in addition to quartz, are pyrite, sphalerite, and galena. The small, but relatively high-grade, pitchblende deposits are separated by large areas of barren vein material. Unlike the Devon-Cornwall district, secondary uranium minerals are only occasionally evident.

Urgeirica Mine and Adjacent Areas, Portugal. During the early period of uranium production when the Cornwall and Front Range areas were contributing a small but significant portion of the world's supply, Portugal ranked second after Joachimsthal among producers of uranium. Unlike the other three of the four producing areas at that time, however, Portuguese production was entirely from secondary uranium minerals in deposits that were not recognized as of primary origin until substantial pitchblende was discovered comparatively recently in the deeper mine workings at Urgeirica. The Portuguese deposits are described here as the first of four groups of such deposits (Portugal; Marysvale, Utah; Central France; and Boulder area, Montana), all originally believed to be secondary because of complete oxidation of the primary minerals to considerable depth, preventing their early detection.

The Portuguese deposits are in a mountainous area about 60 miles square in the north central part of Portugal along the western side of the Spanish tableland or *Meseta*, including the districts of Viseu, Guarda, Belmonte, and Castelo Branco. There are four principal groups of deposits, the most important of which includes the Urgeirica mine, which has been the principal source of uranium production. It is located in the Viseu district on the western edge of the Sierra da Estrella (mountains) near the town of Canas de Senhorim.

The uranium deposits are found in veins, some of which have been traced for several thousand feet, in a white coarse-grained granite of medium age. (Carboniferous)¹ surrounded by folded pre-Cambrian schists. The best ore bodies are found where the veins are straight and open, rather than pinched, as at a bend, or where they are intersected by cross-cutting fractures. Near the principal veins the granite has usually been altered by the hot solutions which deposited the uranium, forming kaolin and fine-grained green sericite. At the surface the veins are marked by zones of kaolin and limonite, and the vein material itself usually has the distinctive dark red jasper, common to most primary uranium deposits, crisscrossed with white quartz veinlets. The uranium mineralization consists entirely of secondary minerals, primarily autunite, torbernite, and uranophane, in rocks and cavities in the vein filling to a depth of more than a hundred feet. At greater depths in the Urgeirica mine, fine-grained, black, powdery pitchblende begins to occur with the secondary minerals

¹ Pennsylvanian and Mississippian combined.

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and becomes more and more common as depth increases, while the secondary minerals gradually diminish. At the deepest levels in the Urgeirica mine the secondary minerals have entirely disappeared, and the ore is a mixture of red jasper, pitchblende, pyrite, galena, sphalerite, and chalcopyrite, together with white quartz.

Other deposits in the Urgeirica group and in the three other groups have surface characteristics similar to those of the Urgeirica mine, and in several of them pitchblende has also been found at depth. Some of the more important of the other deposits are the Reboleiro and Sebadelhe mines near Trancoso, Beira Alta, and the Rosmaneira mine near Belmonte, southern Beira Alta.

Marysvale District, Utah. The Marysvale, Utah district, about 150 miles south of Salt Lake City, was the first entirely new uranium-producing district discovered in the United States (1949) as a result of postwar uranium exploration. The deposits are very similar to the Portuguese deposits and, like them, they were at first considered to be local concentrations of secondary minerals and limited in production possibilities. However, after development had reached a depth of about 60 feet in the Prospector mine, black, sooty pitchblende, similar to the material found at Urgeirica, was encountered.

Although a large number of claims based on showings of secondary minerals at the surface have been staked over a broad area surrounding Marysvale, the principal production has been limited to an area of about one square mile in which there are five operating mines: the Prospector, Bullion-Monarch, Buddy, Freedom No. 1, and Freedom No. 2. These mines are along the western side of a granite-like igneous rock mass called a quartz monzonite. The uranium minerals have been deposited in veins along fracture zones in the monzonite, accompanied by a large amount of alteration of the wall rock to a variety of earthy white to gray clay minerals and in some places by deposition of pyrite and green chlorite. In the veins themselves a purple to black fluorite, darker in color near the better uranium portions of the veins, and red staining, probably due to iron, are common. As in Portugal, the better uranium ore bodies seem to occur at intersections of veins and fractures and where the veins have been opened the widest by faulting. At the Bullion-Monarch mine a large, flat-lying ore body composed of secondary minerals was formed in a complex fracture zone, giving rise to the original idea that there were no underlying primary veins in the region.

The principal uranium minerals are autunite, torbernite, schroëckingerite, and uranophane in the oxidized zone, and pitchblende mixed with pyrite and fluorite at depth. Unlike the deposits so far described, and unlike most primary uranium deposits, the Marysvale deposits are in geologically young rocks rather than in very old rocks. The quartz monzonite host rock is of Tertiary age, and

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it is surrounded and in some places overlain by even younger volcanic rocks. The topography of the area is of the steeply rolling, high, foothill type, with an average elevation of about 5,000 feet.

Massif Central, France. The occurrence of autunite in fractures in granite at Autun, from which the mineral derives its name, on the northeastern edge of a mountainous area called the Massif Central in central France, has been known for nearly one hundred years. Since 1945 several additional and richer uranium deposits have been discovered along the northern edge of the Massif Central as far west as Limoges. These deposits are similar to those of Portugal and Marysville, comprising veins along fractures in granite with yellow secondary minerals in the upper 50 to 100 feet of the veins and pitchblende below. Some of the richest concentrations of uranium minerals occur at the intersections of the veins with narrow bands or *dikes* of diabase¹ which were intruded into the granite.

As in the case of Portugal and Marysville, the principal gangue mineral in the veins is quartz, often the smoky variety, with some fluorite and barite at places. There are few metallic minerals other than of uranium, pyrite being the only common one. The deposits differ from other similar ones in that hard, compact pitchblende usually predominates in the primary ore, sometimes occurring in masses up to 4 inches across, rather than the softer fine-grained, sooty material which is more common at Marysville, Utah, and in Portugal, although in one area the pitchblende is finely disseminated in the quartz veins. Secondary minerals identified in the several deposits, in addition to autunite and torbernite, are the rarer minerals, parsonsite, kasolite, beta-uranotile, curite, renardite, and phosphuranylite. The most important deposits are near Bessines and La Crouzille in Haute-Vienne, north of Limoges; near Grury and Bauzot in Saône-et-Loire, southwest of Autun; and in the vicinity of Lachaux in Puy-de-Dôme, southwest of Vichy.

Boulder Area, Montana. Uranium has been found in a number of localities throughout an area of granite and granite-like rocks about 18 miles wide between Butte and Helena, Montana, called the Boulder batholith. The rocks are relatively young, geologically speaking, approximately the same age (Tertiary) as those in the Marysville district. By 1954, uranium ore had been produced from three properties: the Free Enterprise mine near Boulder, the Wilson Lease or President group of claims, and the Lone Eagle mine near Clancy. The two former deposits represent one type of mineralization in which uranium occurs in small pods and lenses along quartz-filled fracture zones in monzonite, together with pyrite and small amounts of chalcopyrite and molybdenite. The principal uranium minerals are torbernite and autunite, although some

¹ Diabase: a dark-colored igneous rock composed of minerals with a high iron and magnesium content, like amphibole, pyroxene, and mica and calcium feldspar.

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pitchblende and gummite have been found, usually at some depth below the surface. Vein structures carrying the spotty uranium concentrations are strong, and a single structure has been mapped over a distance of several thousand feet. The red staining along the veins, common at many other primary vein deposits, is not conspicuous here. The second type of deposit is represented by the Lone Eagle mine in which pitchblende occurs with fine-grained quartz as thin seams and coatings on fracture surfaces in highly fractured zones in deposits of the sulfides of lead, zinc, and copper.

Uranium minerals have been found at many other localities in the Boulder batholith including the dumps of a number of inactive mines in the region which, until 1928, was an important, although small, producer of gold, silver, copper, lead, and zinc.

Radium Hill, South Australia. The uranium deposits at Radium Hill near Olary, about 250 miles north and slightly east of Adelaide, South Australia, are in many respects unique and therefore of particular interest. The deposits were first worked for radium on a small scale prior to World War I, but when they were looked at as a possible source of uranium during World War II, they were considered by many to be of no further importance because of the refractory, pegmatite-like character of the mineralization and the marginal grade of the ore. Nevertheless, the deposits were intensively explored, and by 1951 an important uranium mine had been developed.

The general geology of the Radium Hill area is similar to that at the important pitchblende localities, comprising very old and highly folded metamorphic rocks. The rocks are so highly metamorphosed, however, that their original character is uncertain. The topography of low, rolling hills is also somewhat similar to that at Shinkolobwe, but the climate is extremely arid and the Australian type of sagebrush and dry washes replace the tall grass and rivers of the Congo.

The deposits themselves are quite different from any other important uranium deposit. They occur in a series of staggered, parallel veins, referred to by geologists as "en echelon." The veins, generally straight and open and from 3 to 6 feet wide, narrow at minor bends and occasionally swell in between the bends to widths up to 12 or 15 feet. The uranium mineral is davidite, which seldom occurs as a pure mineral but rather as a fine-grained, massive, dark-brown or black mixture with ilmenite. This mixture is itself intermixed in the vein with hematite, biotite mica, red feldspar, and quartz, in a manner often closely resembling pegmatite mineralization. However, the veins have great lateral extent, regularity, and depth not found in true pegmatites. Like pegmatite deposits and unlike the other important primary uranium deposits, the veins are believed to have formed at very high temperatures and pressures. The gneiss in which the veins occur has been intruded at various places by dikes

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of rock made up of amphibole (amphibolite) and by small granite bodies of higher than average radioactivity to which the uranium mineralization is believed to be related. Where the veins are intersected by these dikes and by some minor fractures, the ore is reduced in grade and width or even eliminated entirely. This feature, too, is a departure from conditions at most of the other deposits where such features often resulted in better ore bodies.

Tete District, Mozambique (Portuguese East Africa). The only other occurrence of davidite of any significance is located near the town of Tete in west central Mozambique near the border of Southern Rhodesia. Here the davidite is found in a number of scattered pockets, together with several different complex groups of minerals in intrusive igneous rocks of high iron, magnesium, and lime content called *gabbros*. The deposits do not have the continuity in depth or regularity in width of the Radium Hill veins and have produced only a few hundred tons of davidite ore by hand mining methods.

Rum Jungle, Northern Territory, Australia. Another new type of primary uranium deposit was discovered in 1949 in Australia at Rum Jungle, 60 miles south of Darwin on the Darwin-Alice Springs highway, by a prospector who recognized the distinctive colors of secondary uranium minerals in some old copper prospect pits and confirmed the presence of uranium with his Geiger counter. Government geologists recognized the possible importance of the discovery in spite of the limited showing on the surface, and by the end of 1953 the initial development had been completed. The Rum Jungle deposits are, furthermore, in a region that is geologically favorable for additional important finds. The prospector who made the initial discovery, and for whom the best-developed deposit in the vicinity, White's Prospect, is named, was awarded the bonus of 25,000 pounds Australian payable by Australian law for uranium discoveries of sufficient size.

The general geology of Rum Jungle is similar to that at both Eldorado and Shinkolobwe, in that the host rocks are very old, metamorphosed, sedimentary formations. The surrounding country is also somewhat similar to that at Shinkolobwe, with rolling, grass-covered hills and clumps of tropical trees, although because of the low elevation of only a few hundred feet, it is warmer and more tropical in appearance, with considerable jungle-like vegetation in places.

The Rum Jungle ore bodies, however, are not the typical pitchblende vein-type found at Eldorado and Shinkolobwe. The primary mineralization is finely disseminated uraninite with pyrite and copper sulfide minerals, principally chalcopyrite, in highly folded and crushed beds of black slate. Extensive leaching and oxidation of the primary minerals has occurred to a depth of about 30 feet. Secondary uranium and copper minerals occur at the surface but not the spectacular deposits found at Shinkolobwe. Uranium and copper mineralization is exposed or has been uncovered by shallow trenches and shafts at five

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PLATE VI. Prospect Shaft, White's Prospect, Rum Jungle, 1952.

prospects over a distance of approximately 8,000 feet along the slate outcrop on the southern flank of a domal structure of pre-Cambrian slates, quartzites, conglomerates, and limestones. The core of the dome is occupied by a granite mass approximately 8 miles across.

A very large fault, called the Giant's Reef, along which a horizontal movement of $3\frac{1}{4}$ miles took place, cuts both the granite and the sedimentary formations and has caused major folding of the rocks in the area. The presently known deposits are in this folded area, associated with nearly vertical fractures parallel to the folding. A second group of fractures cuts across the folding in the area of the deposits, and in some cases these appear to bound the ore shoots. No uranium mineralization has been found in the fault, but the ore deposits are probably related to it in origin. The mineralized slate is a weak bed that was sheared and crushed under the stress of the folding and faulting in the area rather than broken to form open fissures in which high-grade pitchblende veins could form, as in the case of the stronger and more brittle quartzites and dolomites at Shinkolobwe and the more highly metamorphosed rocks at Eldorado and Joachimsthal. As a result the mineralization is spread throughout the crushed areas of the formation in fine grains, making a lower-grade but still commercial ore. Because of this fine-grained nature of the uraninite deposition, it cannot be seen with the naked eye and can be detected only with the Geiger or scintillation counter or by sampling and assay.

Northern Rhodesia Copper Deposits. The Rhodesian Copper Belt is the largest single copper-producing area in the world and is in many respects similar in geology to the area of the Rum Jungle deposits. The two areas are also very much alike physically and climatically. Five major mines—Roan Antelope, Rokana, Mufulira, N'Changa, and N'Kana—and a host of smaller deposits are located in a belt about 70 miles long just south of the Belgian Congo border, south and east of the area of the Shinkolobwe Mine. The copper mineralization occurs in a slate-like shale bed, which is part of the Mines Series in which the Shinkolobwe ore bodies occur. However, the type of mineralization is strikingly similar to that at Rum Jungle—very small copper sulfide grains, principally chalcocite, chalcopyrite, and bornite, evenly distributed through the favorable shale bed. The mineralized bed has undergone less faulting and crushing than the slate at Rum Jungle, and it is probable, therefore, that the Rum Jungle ore bodies will prove less continuous and extensive. The similarity of the mineralization at the two localities, however, has led to further investigation of uranium occurrences in the Rhodesian copper deposits since the Rum Jungle discovery, and now it appears that at least some of those deposits contain sufficient uraninite with the copper and adjacent to it to permit commercial uranium production.

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FLAT-LYING DEPOSITS IN SEDIMENTARY ROCKS

Until recently, all of the deposits in this group would have been referred to as secondary uranium deposits. However, beginning in about 1949, discoveries of primary uranium minerals in the irregular semi-bedded deposits in the sedimentary formations of the Colorado Plateau area of Colorado, Utah, New Mexico, and Arizona began to be made frequently enough to raise questions in the minds of most geologists as to their origin. The first significant discovery, in the southwestern part of the Colorado Plateau area, involved an entirely new type of deposit, made up in large part of pitchblende, and the primary minerals of other metals, principally copper. These "copper-uranium deposits" are now a substantial source of uranium production in the United States. Subsequent to this discovery, primary uranium minerals were found in at least small amounts in nearly every so-called secondary deposit, including the typical carnotite deposits. Beginning in 1952 as exploration was extended by drilling to greater distances back of the outcrops of the known carnotite deposits and to deeper formations on the Colorado Plateau, a new type of semi-bedded pitchblende deposit was discovered which is expected to exceed in importance all previously known deposits in sedimentary rocks. The largest of these new deposits were discovered in Big Indian Wash, south of Moab, Utah.

In spite of the presence of primary minerals, however, the deposits in the Colorado Plateau area and similar deposits elsewhere are notably different in their occurrence, and quite possibly different in their origin, from the primary or hydrothermal vein deposits. They occur in sedimentary rocks that have not been extensively folded and altered to form metamorphic or partially metamorphosed formations, rather than in granite, in other granite-like igneous rocks, and in metamorphic rocks, as do the vein deposits, and they occur in generally flat-lying, tabular deposits at least roughly parallel to the bedding of the enclosing rock. They are generally lower-grade deposits, although the best of them are higher in uranium content than the poorer vein deposits.

These deposits are also markedly different in occurrence and origin from the very low-grade phosphate, shale, and lignite deposits described in this section and which are more nearly true, bedded, sedimentary deposits, in most cases largely syngenetic, having been formed at the time the enclosing rock itself was deposited. The latter were definitely not formed by hydrothermal solutions and are obviously secondary. The carnotite, copper-uranium, and pitchblende deposits in sandstones, conglomerates, asphaltic sandstones, and limestones, on the other hand, have been moved by solutions of some type into their present locations and are epigenetic deposits. They are bedded to varying degrees, some places conforming closely to the bedding of the enclosing rocks and some places

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partially cutting across the bedding or following in part fractures or other favorable structures.

There is little doubt that surface waters played a big part in the formation of at least some of these deposits, but hydrothermal solutions may have also been required to deposit the primary minerals. Probably the answer will eventually be found to be a combination of the two types of origin. Perhaps the deposits of secondary minerals represent merely oxidized primary deposits. In any event, as in the case of the primary vein deposits, the prospector will be guided by a knowledge of the general characteristics of the different deposits and the conditions and types of rock formations favoring their occurrence.

CARNOTITE DEPOSITS IN SANDSTONES

The carnotite-type deposits in sandstone formations have been the second greatest source of uranium, after the primary vein deposits, and, until recently, the only other important source. With the possible exception of deposits in Turkistan, U.S.S.R., the carnotite deposits of the Colorado Plateau area in the United States were the only important commercial deposits of this type until the discovery in 1951 of similar deposits in South Dakota and Wyoming.

Colorado Plateau. The major source of uranium ore in the United States is the series of sedimentary rocks in the Colorado Plateau area of some 130,000 square miles in Colorado, Utah, Arizona, and New Mexico. Until 1949, the major uranium production had been limited to the carnotite deposits in the Salt Wash sandstone of the Morrison formation in a small area in western Colorado and eastern Utah. Since then, production has come from deposits scattered through a much larger geographic area, including parts of all four states, and carnotite ore has been produced from several different formations.

The presently known area of carnotite mineralization in the Colorado Plateau area is bounded by a line from Craig, in northwest Colorado, south to Albuquerque, New Mexico, west to Williams, Arizona, south of the Grand Canyon, northeast to Vernal, Utah, in the northeast corner of the state, and thence east again to Craig. The deposits occur in the moderately old (Permian) Coconino sandstone through progressively younger formations to the moderately young (Cretaceous) Mesa Verde formation. The most important formations, however, are the Morrison and Entrada of Jurassic age, other formations being more favorable for other types of deposits. The deposits are usually irregular in shape, but with definite, easily recognized boundaries which may or may not conform with the sandstone bedding. They may be tabular, with their greatest dimensions roughly parallel to the bedding of the enclosing rock. In many cases, however, the deposits have become quite thick in the center to form almost round masses, which are referred to as *rolls*. They are commonly thin at the

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edges, often to a paper thin seam, which gives rise to the term *lens*, often used to describe their general shape.

Fossilized tree trunks, branches, or carbonaceous *trash pockets* are almost always found with the better ore bodies, and the carnotite often replaces them,



PLATE VII. Colorado Plateau Deposits and Mills. Courtesy Union Carbide and Carbon Corp.

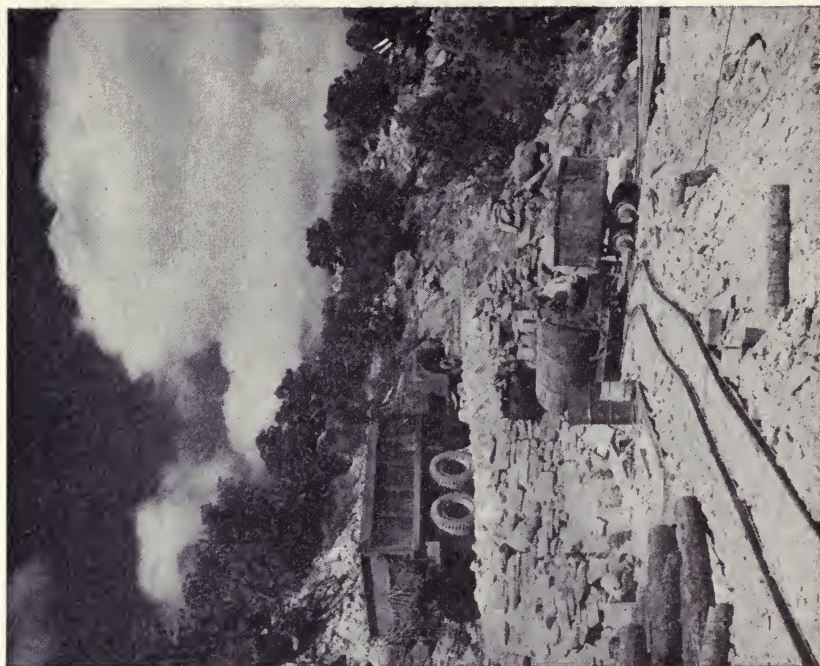


PLATE VIII A. Uranium Mining on the Colorado Plateau. Courtesy Union Carbide and Carbon Corp.

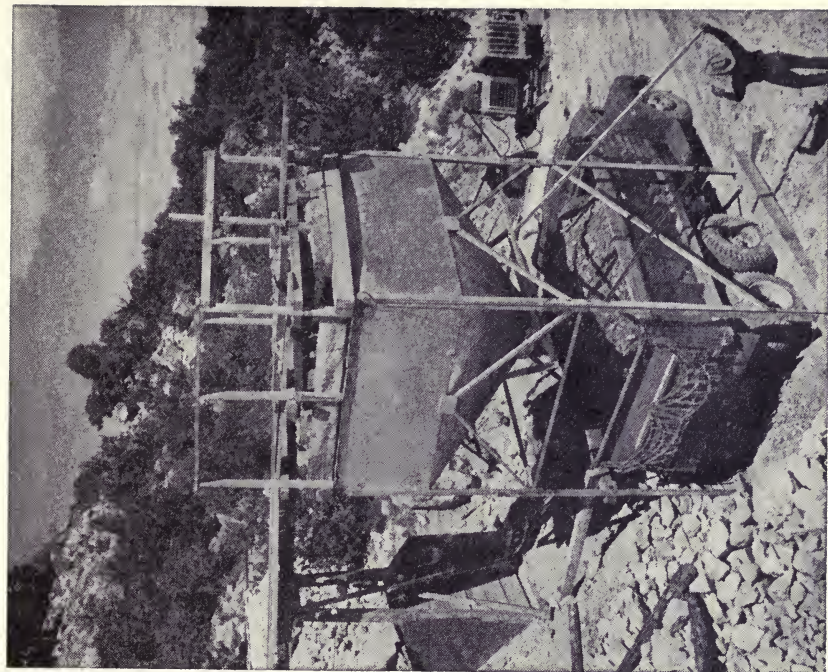


PLATE VIII.B. Uranium Mining on the Colorado Plateau. Courtesy Union Carbide and Carbon Corp.

but ore is not always found with the fossilized material. The deposits also often favor the thicker parts of a sandstone and a location near a shale or mudstone lens or parting. The deposits vary tremendously in size—from a fraction of an inch to several feet in thickness and from a few feet to several hundred feet in length or width—and have an extremely spotty distribution.

In the higher-grade deposits, the yellow color of carnotite is always visible, and some of the deposits are quite a spectacular bright yellow. The carnotite in the lower-grade deposits, however, may be so finely spread throughout the rock as to be masked by the buff or gray color of the sandstone. The carnotite may also be masked by a preponderance of the dark vanadium minerals. This is particularly true in the roscoelite deposits (named for the predominant vanadium mineral) of the Entrada formation in the Rifle and Placerville, Colorado, districts, which are primarily vanadium deposits and usually contain less than 0.10 per cent U_3O_8 . The uranium content of the average carnotite deposit in the Morrison formation will be between 0.10 and 0.5 per cent U_3O_8 and will contain 1.5 to 2 per cent V_2O_5 . Minor amounts of tyuyamunite and some of the more rare secondary minerals have been identified in the deposits. The vanadium minerals, vanoxite, and hewettite, often occur in both the roscoelite and carnotite deposits.

The geologic setting of the carnotite deposits, as in the case of all other deposits, determines primarily the methods of exploration required. Early experience in the Colorado Plateau indicated that carnotite deposits could be located at the rim outcrops of the flat-lying Salt Wash sandstone member of the Morrison formation along the rims of the numerous high mesas in the area. In the early history of the area, discovery was simply a matter of examination on foot of the thousands of miles of Salt Wash rim. An early view, widely shared by miners and prospectors, held that ore bodies were limited to zones near rim outcrops. As information about the occurrence of the ores increased as a result of mining operations and intensified exploration, it was demonstrated, however, that ore bodies are found throughout the Salt Wash sandstone, regardless of the proximity of outcrops.

Ore discovery is made difficult by the size and shape of the ore bodies, their erratic distribution, and their frequent considerable depth below the surface. In exploring for new deposits, the prospector is, of course, immediately interested in locating outcrops showing uranium mineralization. Examination of the core, obtained from drilling, together with information assembled from the nearest outcrops of favorable formation will also often permit selection of ground which is considered favorable for ore deposition back of the mesa rims. For example, if the drill core from the bed in which ore is thought to occur contains more than 50 per cent shale, the ore is not considered favorable because the rock is not sufficiently permeable to have permitted passage of ore-forming



PLATE IX. Plant of the United States Vanadium Co. at Uravan, Colorado. *Courtesy Union Carbide and Carbon Corp.*

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solutions. If the sandstone lenses are thin, even where there is more than 50 per cent sandstone, it is unlikely that any one lens contains enough permeable sandstone to have permitted the formation of a commercial ore body.

Experience has shown that if the mudstone below the sandstone is red, red-brown, or chocolate-brown, there is little chance of finding ore. On the other hand, if there is a thick, medium-grained, clean sandstone, which has considerable carbonaceous matter with a thick green mudstone below it, there is a good possibility of finding nearby ore. The newer discoveries, particularly those containing primary minerals, also give added weight to the possibility that structural features, such as faults, may play an important role in determining the location of a deposit.

Black Hills Area, South Dakota. The discovery of carnotite in 1951 in Craven Canyon near Edgemont, South Dakota, at the southwest corner of the Black Hills, was the first instance of commercial carnotite deposits of any significance found entirely outside the Colorado Plateau area and resulted in the development of an entirely new carnotite mining area. By 1954 carnotite had been found along the western fringe of the Black Hills as far north as Aladdin, Wyoming, a distance of about 100 miles. Small occurrences have also been found in the Badlands of Pennington County, South Dakota, at the southeastern edge of the Black Hills.

The carnotite deposits of this area are similar in many respects to the smaller carnotite deposits of the Colorado Plateau; none has been found to date as large or as rich in uranium or vanadium as the better Plateau deposits. Yellow carnotite staining of fracture surfaces and outcrops of the sandstone is possibly more prevalent, relative to the size and grade of the deposits, than in the Colorado Plateau area, and it may in some cases mislead the prospector new to the area. Often the stains are unrelated to or at least considerably removed from the better ore deposits. The yellow carnotite stains may also be accompanied by a green stain or the yellowish- to reddish-brown staining of limonite and the black stain of manganese oxide.

The deposits occur primarily in the Lakota and overlying Fuson sandstone formations, which are slightly younger (Cretaceous) than the Morrison formation, which is the major ore-bearing formation of the Colorado Plateau. The Morrison formation immediately underlies the Lakota in the Black Hills area and may also prove to be an important ore-bearing formation. The Lakota and Fuson formations are primarily white to buff colored, fine-grained sandstones very similar in appearance to the Salt Wash of the Morrison.

Powder River Basin, Wyoming. The first discovery of an entirely new uranium district by means of an air-borne Geiger counter was made in 1950 by the U. S. Geological Survey at Pumpkin Buttes in the southwestern part of the Powder River Basin, Wyoming, near the town of Midwest. Ground in-

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vestigation in 1951 and 1952 by the U.S.G.S. revealed a number of small carnotite rolls similar to those found on the Colorado Plateau, as well as some small tabular carnotite deposits also similar to the Plateau type, but much smaller and lower in grade, in the relatively young (Eocene) Wasatch sandstone formation. The higher-grade deposits, samples from some of which assayed as high as 10 to 15 per cent U_3O_8 , occur in soft, tan to pink sandstone and contain in addition to the yellow carnotite a heavy black mineral. The rolls are generally parallel to the bedding of the sandstone and are roughly tabular, but very irregular, in shape. Only the rolls, which usually have less than one ton of ore, contain commercial grade ore.

In 1953, a new group of deposits was discovered to the southeast of Midwest in Converse County. These deposits are larger and more continuous and give promise of significant production. The favorable Wasatch formation extends over several thousand square miles of the Powder River Basin, any part of which might contain additional deposits.

Ferghana, U.S.S.R. Although carnotite has been found in small quantities at a large number of localities throughout the world, often associated with deposits of the other uranium minerals, the only known commercial deposits, other than those in the United States, are in Soviet Russia. Scattered carnotite deposits occur over an area of some 1,000 square miles around the towns of Kokand and Ferghana in a mountainous, semi-arid region in the extreme southwestern part of Siberia near the borders of Afghanistan, India, and Sinkiang. The deposits occur in a greenish-gray sandstone bed about 20 feet thick and younger (Miocene) than any other formation in which carnotite ore is known to occur. The rocks of the area have been moderately folded, and the ore deposits are found along rock outcrops where rivers have cut through the formations. The carnotite is usually most concentrated near the remains of fossil logs and other vegetation, and the ore bodies consist of thin seams or irregular pockets or lenses often with a central core or roll of thicker, higher-grade ore. The favorable ore-bearing sandstone has frequent shale or mudstone lenses near which the fossil material and ore are often found.

These deposits are very similar to those of the Colorado Plateau region of the United States, and although the information available prior to World War II indicated that they were smaller in size and limited to a much smaller area, it is quite possible that further exploration since that time has resulted in increasing substantially the potential uranium production of the area. The principal mineral is carnotite, with some tyuyamunite, other vanadium-bearing minerals and varying amounts of copper minerals. The latter are sometimes present in sufficient quantity to give a greenish color to the ore and suggest a similarity to the copper-uranium deposits of the southwestern Colorado Plateau.

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Mauch Chunk, Pennsylvania. The earliest discovery of carnotite in the United States was reported in the geologic literature in 1874 from a location in Carbon County in eastern Pennsylvania near the town of Mauch Chunk. Until recently, this occurrence was considered to be of scientific interest only. However, since 1951 two new uranium discoveries have been made in road cuts, one in the Pottsville conglomerate about a half mile northwest of Mauch Chunk, and the other in the Pocono sandstone a half mile southeast of the town. Development work on the former has revealed several hundred feet of mineralization, sections of which are of commercial grade. Although the original report concerned carnotite, these two occurrences appear to contain considerable autunite, as well as an unidentified, black, radioactive mineral in the unweathered parts.

The Pocono formation is a medium-grained, clean, gray-white sandstone, and the Pottsville is a coarser-grained sandstone or, more properly, a relatively fine-grained conglomerate, with a reddish color. Both formations outcrop over wide areas of eastern Pennsylvania along the spectacular northeast-southwest trending ridges of the area. The rocks are relatively old (Carboniferous) compared to the carnotite-bearing formations of the Colorado Plateau, the Black Hills area, and the Powder River Basin. The formations are steeply tilted, and the uranium mineralization is spotty and cuts across the bedding of the rocks, usually along fracture zones. The outcrops of the mineralized zones are typically yellow in color. These deposits are only generally similar to the typical carnotite deposits and may more properly belong to the oxidized deposits described in following pages.

Garo, Park County, Colorado. The Garo deposit consists of carnotite and tyuyamunite in yellow fracture coatings and in semi-bedded ore bodies in a medium- to coarse-grained sandstone. The sandstone has been tilted steeply by regional folding and broken by numerous faults. Other minerals present are black and red vanadium minerals and the secondary copper minerals, malachite, and azurite. The deposit was first discovered during World War I and produced about 40 tons of relatively high-grade carnotite ore shortly thereafter. It lies in an area of sedimentary rocks forming a broad valley called South Park at an elevation of 9,000 feet southeast of Leadville, Colorado, surrounded by the highest ranges of the Rocky Mountains.

Although the mineralogy differs from the typical carnotite deposits and has some similarity to the copper-uranium deposits, the ore bodies appear to be more related to the former. Ore deposition also appears to have more relationship to fracturing of the sandstone than either the carnotite or copper-uranium deposits, and in this respect the deposits resemble those at Mauch Chunk. The Garo deposits are also in a considerably older (Permian) formation

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than the majority of the carnotite deposits of the Colorado Plateau, the eastern edge of which is about 100 miles to the west.

DEPOSITS IN ASPHALTIC SANDSTONES

Although the association of uranium with carbon is very common in a large variety of deposits, and in many cases undoubtedly has a bearing on the origin and manner of formation of uranium ore, there is only one commercial uranium occurrence intimately and consistently related to asphaltic materials and deserving special mention as a separate type of deposit. Strangely enough, most other known asphalt deposits do not contain significant amounts of uranium.

San Rafael Swell Area, Utah. Uranium deposits in asphaltic sandstone beds occur in the San Rafael Swell area of east-central Utah in the west-central part of the Colorado Plateau region. For the most part, they are confined to the Shinarump formation, which also contains most of the copper-uranium deposits to be described later. This area has both typical carnotite-type deposits and copper-uranium deposits, in addition to the asphaltic type. On the east side of the Swell (domal uplift) at Temple Mountain, uranium ore has been deposited along faults and fissures which definitely control its position. On the west side of the Swell, the larger ore bodies lie within a few thousand feet of major faults.

The distribution of the asphaltic ore deposits is erratic, and the concentrations are generally no more than a few hundred feet in length and width and not more than 3 feet in thickness. They are very similar structurally to the carnotite and copper-uranium deposits and are largely confined to porous, medium- to coarse-grained sandstone lenses or conglomerates containing asphaltic material between the sand grains or pebbles. As a rule, the uranium concentrations coincide with the highly asphaltic beds, most of the uranium being closely associated with seams or other accumulations of asphaltic material. Mineralized fossil logs, twigs, and leaves have been found in some of the ore bodies.

Although several recognizable secondary uranium minerals, including carnotite, have been identified associated with a variety of secondary iron, copper, and cobalt minerals, much of the uranium, together with vanadium, occurs as an integral part of the black asphalt, which appears to be partly made up of the vanadium minerals, corvusite and rauvite, and is closely associated with considerable pyrite. In other areas of the Swell, uranium forms a part of the pure asphalt associated with small amounts of zeunerite and copper minerals. Gypsum is present in all of the deposits.

For the most part, these deposits have about the same uranium content as the carnotite deposits, although some very large deposits, considerably lower

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in grade, are known. The best-known occurrences are in the Temple Mountain district on the east side of the San Rafael Swell, but evidence indicates that mineralization may have occurred at many places around the entire flank of the Swell.

DEPOSITS IN LIMESTONES

As in the case of the deposits in asphaltic sandstones, there is only one good example of flat-lying uranium deposits in limestones. The deposit at Tyuya Muyun near Ferghana in the U.S.S.R. is also in limestone, but because it is confined to a major fracture zone, rather than having bedded characteristics, it has been included in a separate category.

Grants District, New Mexico. The uranium deposits of the Grants, New Mexico, district in the extreme southeast corner of the Colorado Plateau region are found in a thin, partially marbleized limestone forming the upper portion of the Todilto formation, which caps many of the low mesas and benches extending along the north side of a highland known as the Zuni Uplift. Within the limestone, uranium occurs in uranophane and tyuyamunite, coating minor fractures and bedding planes with a typical yellow color. The richest concentrations are commonly in rolls within the formation, similar in appearance to the carnotite rolls. Minor occurrences of pitchblende have been found with the secondary minerals within finely crystalline limestone. Other minerals present are fluorite, calcite, hematite, and limonite. The ore lies within 2 to 12 feet of the surface and is ideally situated for cheap strip mining operations. The deposits are somewhat lower in grade than the average carnotite deposits.

The discovery of these deposits in 1949 created a great deal of interest because of their occurrence in limestone and because they greatly extended the geographic limits of known ore deposits on the Colorado Plateau. The extensive outcrops of the favorable formation afford wide areas of favorable ground for the discovery of additional mineralized areas. Prospecting in this area also revealed the existence of typical carnotite deposits of the Colorado Plateau type in the sandstone formations overlying the Todilto formation and covering a much broader area. Discoveries of deposits in sandstone in 1952 and 1953, particularly those on the Laguna Indian Reservation east of Grants, may exceed in importance the original limestone deposits.

PITCHBLENDE DEPOSITS IN SANDSTONES

The first extensive flat-lying pitchblende deposit in sandstones unrelated to copper mineralization was discovered in Big Indian Wash, south of La Sal, Utah, in the central Colorado Plateau area in 1952. This deposit represented the most important new uranium discovery in the United States and raised anew the question of origin of the Plateau deposits. By the end of 1953 several additional deposits of the same type had been discovered in the area, and it

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had become apparent that other areas of the Colorado Plateau might also contain such deposits.

The deposits are in the Chinle formation of Triassic age comprising mixed sandstones, conglomerates, and mudstones or shales which, with the overlying Shinarump conglomerate, forms the host rock for the copper-uranium deposits elsewhere on the Plateau. The ore-bearing beds have many similarities to the channels in which the copper-uranium deposits occur. However, these deposits do not contain appreciable copper. The pitchblende has been deposited in the sandstone portions of the formation together with pyrite, vanoxite (a vanadium oxide), a vanadium silicate, and tyuyamunite, carnotite and becquerelite, in beds commonly 10 to 15 feet thick. A considerable amount of carbonaceous material, minor fluorite and traces of several metallic elements occur in the ore.

The general configuration and structural characteristics of the deposits are similar to the largest carnotite deposits, but the grade of the ore is somewhat higher. The deposits are located along the flank of a major geologic structure called the Lisbon Valley anticline¹ and within a mile or two of the major Lisbon Valley fault which parallels the axis of the anticline. The relationship, if any, of the deposits to the fault has not been determined.

COPPER-URANIUM DEPOSITS

The copper-uranium deposits occur at many localities in conglomerate, sandstone, and shale formations of Triassic age in the western and southern parts of the Colorado Plateau. Most of these deposits are in southern Utah and northern Arizona in the Moenkopi, Shinarump, or Chinle formations. These formations are not uniform in thickness like many such formations, but thin and thicken rapidly from one place to another. This characteristic is believed to indicate rapid deposition in and near stream channels. As in the carnotite deposits, the mineral concentrations appear to be in or near the thickest and lowest parts of the sandstone or conglomerate beds along the ancient stream channelways. The channels, however, are larger and more persistent and therefore more evident than in the Salt Wash carnotite deposits. Like the carnotites, the deposits are spotty and erratic in distribution.

One of the characteristic features of the copper-uranium deposits is the mineralogic difference between the relatively unoxidized and the oxidized portions of the deposits. The unweathered primary minerals include pitchblende and a variety of iron and copper sulfides. At the weathered outcrops along the mesa rims, however, the principal minerals are the bright-colored, secondary minerals of uranium, copper, and iron. Among the secondary uranium minerals, torbernite, johannite, uranophane, becquerelite, and zippeite

¹ An up-arched fold in the rocks.

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have been identified in the deposits. The secondary copper minerals are malachite, azurite, and the other similar green and blue minerals.

From the deposits so far developed, it appears that the weathered rim outcrops are lower in uranium, and improvement in grade can be expected as a deposit is mined back from the rim. Copper-uranium deposits that appear to consist of several thousands of tons can probably be considered potential producers if the oxidized rim outcrops assay more than 0.05 per cent U_3O_8 . The unoxidized portions of such deposits may contain ore averaging several tenths of 1 per cent U_3O_8 .

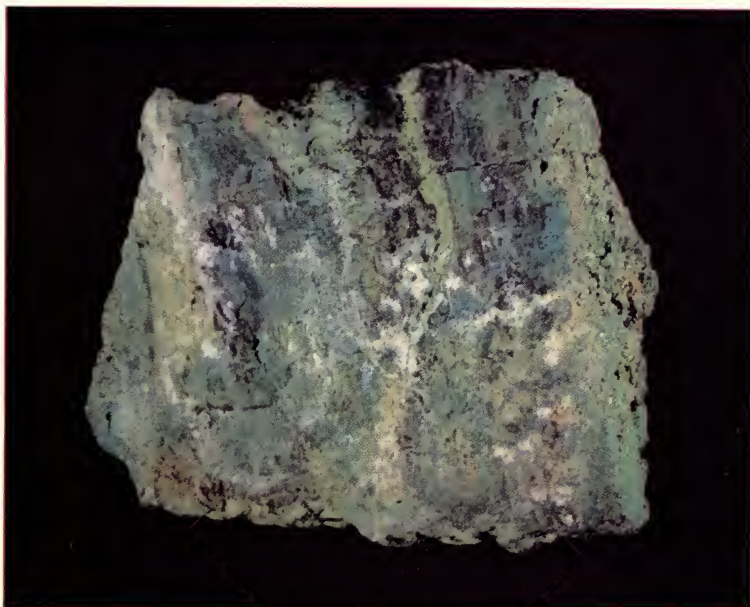
The Shinarump conglomerate in which most of the deposits are found is a coarse-grained, poorly cemented, white sandstone containing frequent lenses composed of coarse pebbles up to 2 inches in diameter. Petrified logs and wood fragments are common throughout the formation. The Moenkopi and Chinle formations, which also contain some deposits and lie below and above the Shinarump respectively, are mixed shales and sandstones of reddish-brown and red (Moenkopi) and blue-gray or purple (Chinle). Some of the best deposits occur at the contact between the Shinarump and Moenkopi formations, where the Shinarump was deposited in the deep channels cut into the Moenkopi.

The deposits are often extremely spotty in uranium content, especially at the outcrop. A mineralized bed may contain 1 per cent or more uranium at one point and contain no uranium a few feet away, with little difference in appearance. The characteristic green copper staining which is often difficult to distinguish from torbernite coatings is not in itself a reliable indication of uranium. Highly copper-stained beds may contain little or no uranium, and likewise some deposits containing appreciable uranium may be lacking in copper. The primary uranium and copper minerals are almost never found at the outcrops, and it is impossible to tell from the outcrop whether they will turn out to be present at all in a given deposit.

The best-known copper-uranium deposits and the most mining and prospecting activity are in the White Canyon-Red Canyon district of southeastern Utah near the town of Hite and in the San Rafael Swell area west of Greenriver, Utah. One of the best known deposits, and one of the largest mines of any type, the Happy Jack mine, is located in White Canyon. Other areas of copper-uranium mineralization are the Silver Reef district, Washington County, southwest Utah; the Capitol Reef and Circle Cliffs areas south of the San Rafael Swell; and the Marble Canyon-Lee's Ferry area of northern Arizona.

DEPOSITS OF URANIUM PHOSPHATES AND ARSENATES IN SANDSTONES

A new type of uranium deposit in sedimentary rocks was discovered in 1953 near the town of Riverton in the Wind River Basin, Wyoming. Uranium occurs



Pitchblende Associated With Copper Minerals—Happy Jack Mine, Utah
From *Prospecting for Uranium*, by U. S. Atomic
Energy Comm. and U. S. Geological Survey, 1951.

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principally in heretofore relatively rare phosphate and arsenates tentatively identified as uranocircite, phosphuranylite, and uranospinite in the arkosic¹ Wind River sandstone of Eocene age. Some uranium is also contained in fluorapatite, an accessory constituent of the sandstone.

Since the original discovery, numerous deposits have been found over a wide area in the Wind River Basin bounded by Lander, Thermopolis, and Casper, and in several formations of older age than the Wind River. The deposits are generally similar, except for the mineralogy, to the carnotite deposits of the Powder River Basin to the east. The uranium arsenates and phosphates are in the form of very recent surface and fracture coatings in the sandstone. This recent movement and deposition by the uranium-bearing solutions has resulted in wide variations in the degree of radioactive equilibrium, and consequently counter readings in most cases are completely unreliable in estimating uranium content.

DEPOSITS IN PHOSPHATE ROCK

Uranium occurs in phosphate formations, originally deposited in the sea, of all geologic ages and in many different parts of the world. These deposits are referred to as marine *phosphorites*, and together with the marine black shales represent the only truly sedimentary deposits of uranium. Because the uranium was deposited at the same time as the rock formation in which it is found, the deposits are *syngenetic*. Uranium-bearing phosphorites are reported at a great number of localities in the U.S.S.R., particularly in central and northern European Russia; in North Africa in Egypt, Algeria, Tunisia, Morocco, and Nigeria; and in the Phosphoria formation of the northwestern United States and in the Bone Valley and Hawthorne formations of central Florida. Uranium also occurs in phosphate nodules in shaly limestones in Devon, England; in the black shales of the English Midlands; and in Oklahoma and Kansas. The deposits of this type so far discovered do not appear as favorable for uranium recovery as the phosphorites. Phosphate deposits that were not of marine origin, such as those in Tennessee, formed by weathering of surface rocks; the *hardrock* phosphates of Florida as distinguished from the more important Florida *pebble* phosphates; and the phosphate-bearing limestones and guano deposits of the Pacific islands do not contain appreciable uranium.

The uranium-bearing phosphorites range in age from relatively old (Paleozoic) to quite young (Pliocene), and all seem to be equally favorable for uranium. With some exceptions, the beds highest in phosphate content in a given area are likely to be highest in uranium content. In some cases this has been modified through removal of phosphate by surface water after the forma-

¹ Formed directly from disintegrated granite and composed largely of angular or sub-angular grains of quartz and feldspar rather than well-rounded quartz grains.

tion was deposited, resulting in a higher uranium and lower phosphate content.

The uranium in all of the deposits appears to occur primarily in the principal phosphate mineral, fluorapatite [$(\text{CaF})\text{Ca}_4(\text{PO}_4)_3$], although occasionally it is dissolved from that mineral by ground waters and deposited as stains composed of one or more of the secondary uranium minerals. Some uranium is probably also associated with clay minerals and in organic material. The prospector looking for uranium-bearing phosphorites must rely primarily on identifying the phosphate rock and having it assayed for uranium, or on the use of the counter to identify the higher-than-normal radioactivity of the formation.

So far as is known, the only attempt at commercial production of uranium from phosphates, as a by-product of the mining and processing of phosphate rock for fertilizer, has been in the United States.

Florida Land Pebble Phosphates. The phosphates of central Florida are flat-lying, light-colored beds with the appearance of mixed sand, small pebbles and clay. These deposits, the richest of which are located in the Plant City-Lakeland-Bartow district east of Tampa, provided the first uranium production from phosphates in 1952. Phosphate occurs in the Hawthorne formation (Miocene) and the very young overlying Bone Valley formation (Pliocene). The Bone Valley contains most of the "land pebble" deposits which contain the most uranium, while the *hardrock* phosphates of lower uranium content are found in the Hawthorne. The best uranium values in the Bone Valley are in the upper part of the formation in what is called the *leached zone*, apparently enriched in uranium through removal of other constituents by ground waters after deposition.

Northwest Phosphates. The northwest phosphates comprise the Phosphoria formation of southwestern Montana, southeastern Idaho, western Wyoming, and northern Utah. The uranium content varies considerably from one area to another; it increases, for example, westward from Wyoming into Idaho and decreases westward in Montana. The areas of highest uranium content are in the vicinity of Bear Lake, Idaho and Utah, and immediately adjacent areas of Wyoming, and in the Helena-Anaconda-Butte-Dillon area of Montana. The Phosphoria formation of the northwest is largely dark in color, very fine-grained, relatively hard, and often folded so that the beds dip at steep angles. The formation is usually from 200 to 500 feet thick, and even the beds of highest phosphate content are usually contaminated with shaly and organic material, lime, and chert. The more limy beds are usually lacking in uranium. Unlike the Florida deposits, the northwest phosphates contain a variety of metals other than uranium in small quantities. Vanadium has been recovered commercially.

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DEPOSITS IN BLACK SHALES

Uranium-bearing black shales, like the phosphorites, are syngenetic deposits of marine origin. Unlike the phosphorites, however, only a few of the numerous black shale formations contain appreciable uranium, and most of those that do are geologically old formations. The uranium content of the black shales is generally lower than that of the phosphorites, nearly always less than one-fifth pound per ton, with the exception of the alum (kölm) shale of Sweden, which is reported to contain up to more than one-half pound per ton. The uranium content is also much more consistent within a given bed, showing little variation over large distances. All of the uranium-bearing black shales contain petroleum, but those having the highest oil content appear to have the least uranium. The uranium is usually confined to one particular bed representing only part of the full thickness of a given black shale formation.

The uranium-bearing black shales are black or very dark in color, rich in organic material and iron sulfides, usually pyrite or marcasite, and contain very little lime. A freshly broken piece immediately after striking with a hammer, will usually give an odor similar to crude oil, but will seldom have enough lime to effervesce when dilute hydrochloric acid is applied. At the present time only the bituminous shales are known to contain appreciable uranium; the carbonaceous or coaly type of black shale is essentially barren.

The uranium is not present as a distinct mineral, but rather as an integral part of the constituents of the rock, probably the clay minerals or the organic matter. As a result, prospectors will have to rely on identification of the favorable rock type and the use of the counter to detect abnormal radioactivity. Because of the low uranium content of shales, the counter reading may well be less than over granite.

Like the uranium-bearing phosphorites, the black shales, or the uranium-bearing portions of them, are relatively thin formations as compared to other strata formed over the same period of time. This slowness of deposition is believed to be the answer to the unusual amount of uranium present. Assuming a steady rate of precipitation of uranium from sea water, the slower the deposition of shale or phosphate, and consequently the less rock formed in a given time, the higher the uranium concentration. This slow marine deposition also results in broad continuous beds with little variation in thickness except over great distances. Although such formations were originally deposited in a horizontal position, they may have since been subjected to a great deal of folding. This has been the case with parts of the Chattanooga shale, which in some places has been turned completely on end.

Kölm-bearing Alum Shales of Sweden. Uranium was found in the alum

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shale of southern Sweden in 1893, richer parts of which were first mined in 1909 for radium; experimental production of uranium from the Swedish shales was only recently effected. The alum shale is a very old formation (Cambrian). Although the shale itself is reported to contain somewhat more uranium than the black shales of the United States so far known, it is also unique in having nodules and small lenses of nearly pure pitch-black hydrocarbon that often contain as much as one-half of 1 per cent uranium. These nodules can be separated from the shale for limited production, thus effecting a several-fold increase in uranium content in the material treated. The uranium-bearing shales are in southern Sweden in Västergötland, Östergötland, Narke, and Skane.

Russian Shales. Uranium is known to occur in formations equivalent to the Swedish alum shale across the Baltic Sea in Estonia and in the Leningrad district of the U.S.S.R. These shales, like most other uranium-bearing black shales, are believed to have the uranium restricted to thin high-hydrocarbon beds and to those formations that are not the highest in oil content.

Chattanooga Shale and Other Shales of the United States. In the United States the best occurrence of uranium in shales is the Chattanooga shale in the Sparta-Smithville-McMinnville area midway between Knoxville and Nashville, Tennessee. Outcrops of the Chattanooga or its equivalent in Alabama, Georgia, Kentucky, Illinois, Indiana, Michigan, and Ohio, including the Sunbury, New Albany, Utica, and Antrim shales also contain detectable, but less, uranium. In those areas where the Chattanooga shale has the highest uranium content, the formation is usually less than 100 feet thick, and the uranium-bearing portion may be less than 20 feet in thickness, with very thin beds of a few inches to a few feet, high in hydrocarbon, having the highest uranium content. The Woodford formation of Oklahoma, the Nonesuch shale of Michigan, and Calico Bluff formation of east-central Alaska, as well as several others throughout the great plains and mountain states also contain traces of uranium. There is always the possibility that parts of some of these shales will be found to have a higher uranium content than the Chattanooga. The oil shales of Rifle, Colorado, do not contain uranium.

DEPOSITS IN LIGNITES AND COALS

Most coals and lignites are not appreciably radioactive—in fact, prior to recent discoveries, coals and lignites in general were regarded as among the least radioactive of all rocks. However, certain lignites and coals in the Dakotas, Wyoming, Idaho, Montana, New Mexico, Nevada, and Colorado have now been found to contain in places up to as much as one pound of uranium per ton. Recent studies of these deposits suggest that they were not radioactive when originally deposited, but that the uranium was chemically absorbed after

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deposition from waters moving downward through slightly radioactive overlying rocks, mainly volcanics. For this reason the uranium distribution is irregular and varies with such features as joints or fractures and the presence or absence of interbedded permeable or impermeable rocks.

Dakota and Wyoming Lignites. The best lignites now known, so far as uranium is concerned, are those of Tertiary age at Slim Buttes, Harding County, South Dakota, and in the Red Desert area near Wamsutter, southern Wyoming. The uranium in these lignite deposits is not only irregularly distributed due to deposition by ground waters, but the lignite beds themselves are often very thin—only a few inches or a very few feet thick—and separated by sandstone or shale beds. This reduces the over-all grade of the material in a given deposit, since in most cases the individual beds cannot be mined separately, and restricts the possibilities of development to a few thicker than average beds that may also have a slightly higher than average uranium content. Utilization of the lignites as a source for uranium will probably depend upon many factors, among which are the ease with which uranium can be chemically removed from the ash after burning and the large-scale need for the lignites as a fuel for industrial power plants. A few of the uranium-bearing lignite deposits have been mined on a small scale for fuel.

Like the phosphates and shales, the problem of prospecting for uranium-bearing lignites usually involves identification of the lignite, which is a brown to black, coaly material, and upon detection of radioactivity. Only rarely can staining by secondary minerals be visually detected. Unlike the uranium-bearing phosphates which are of all ages, and the uranium-bearing black shales, most of which are older formations, the majority of the uranium-bearing lignite deposits are of younger Tertiary age.

Old Leyden Coal Mine, Colorado. Uranium mineralization, predominantly carnotite, occurs in the workings of the Old Leyden coal mine near Golden, Colorado. It is found to some extent in fractures in the coal itself, but the better concentrations are in sandstone beds associated closely with the coal. This deposit, and La Ventana Mesa described below, were the only examples of uranium associated with coal in concentrations that might prove to be commercial known in 1953, although others may eventually be found. The eastern coals, however, with the possible exceptions of those deposits in the vicinity of Mauch Chunk, Pennsylvania, do not appear to have much possibility for uranium.

La Ventana Mesa, New Mexico. Uranium in spotty concentrations equal in grade to the Colorado Plateau deposits was discovered in 1951 in a thin (2 to 8 inches) seam of coal on La Ventana Mesa, 62 miles northwest of Albuquerque, New Mexico. The coal seam separates a sandstone bed above from a shale bed below in the Mesa Verde formation of Tertiary age. Both

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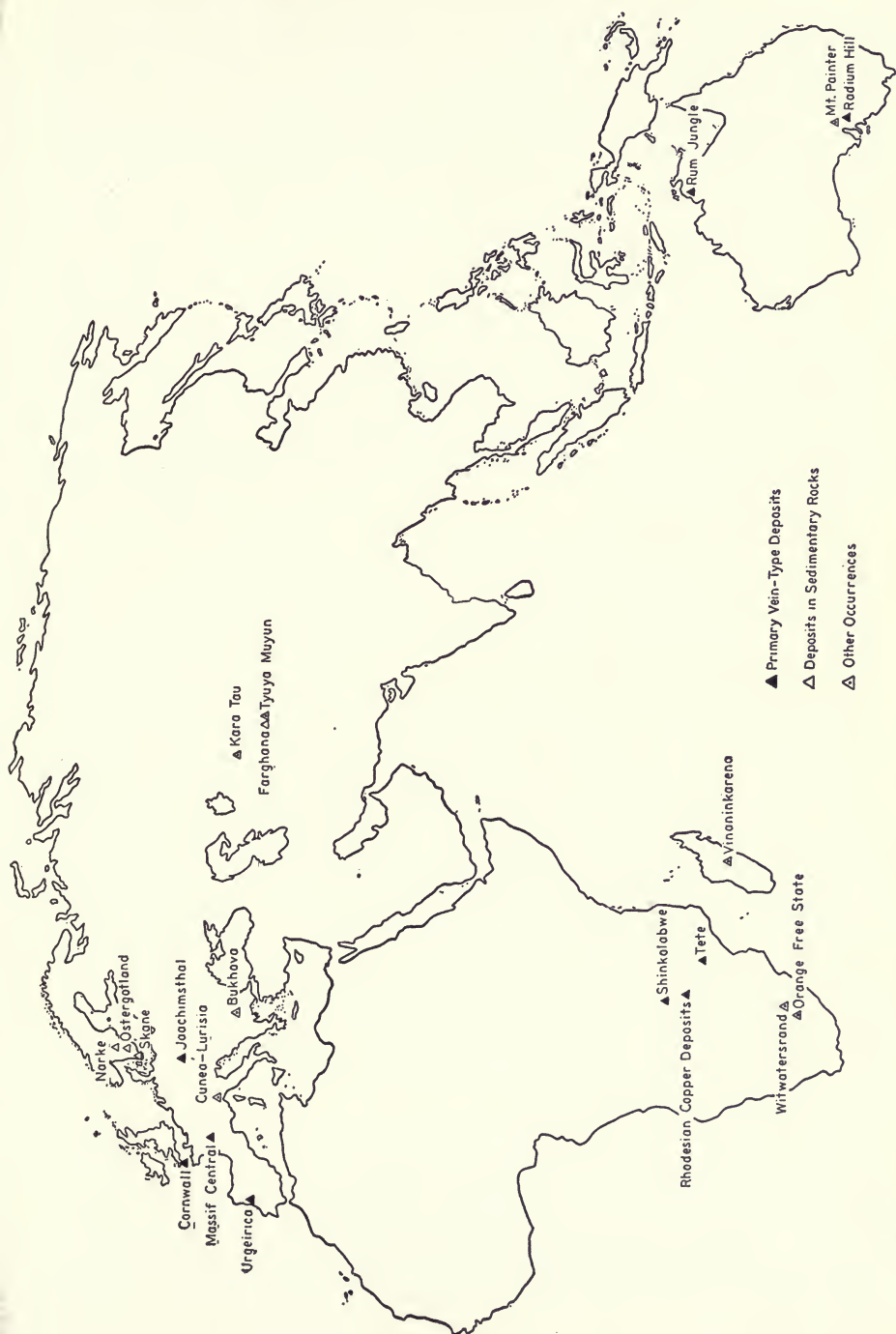


PLATE XB. Productive and other Significant Deposits of Uranium.

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the sandstone and the shale are mineralized, but to a lesser degree than the coal. Although the outcrops originally discovered were too thin and too low in average uranium content to be of commercial value, the high values found at certain spots indicate that mineable ore might exist in the area. The best samples from this deposit had higher uranium values than those from any other coal or lignite deposit.

OTHER URANIUM DEPOSITS

In addition to the deposits of obvious hydrothermal origin and the flat-lying deposits in sedimentary rocks already described, there are twelve other deposits falling into four general groups that do not quite fit into any of the categories already mentioned. Each of these deposits, or groups of deposits, has one or more characteristics in common with the major types already described, and perhaps, as our knowledge about them increases, they will be seen to fit better into one of those categories. However, for the present they are described separately.

DEPOSITS OF SECONDARY MINERALS IN ROCK FRACTURES

These are the deposits of secondary uranium minerals formed at low temperatures and pressures in fractures and fracture zones in surface rocks by ground waters which have moved the uranium varying distances from its original, and often unknown, source. They are sometimes called *oxidized secondary deposits*. The predominant uranium minerals are usually the phosphates like autunite and torbernite. Almost any secondary mineral may be found in such deposits, however, and uranophane, tyuyamunite, and carnotite are the next most common. The gangue minerals are usually quartz and calcite, with occasional fluorite and barite. The deposits are generally yellow and green, although often with brown iron staining and may be spectacular in their coloration, frequently leading to an overestimation of their importance. They are very similar in appearance to the oxidized portions of hydrothermal vein deposits, particularly those at Marysvale, Utah, and Urgeirica, Portugal, which were originally classed in this group before it was known that primary minerals occurred at depth. Some of the deposits listed here may soon also prove to be merely the surface oxidation in place of primary deposits. The deposits all occur in arid or semi-arid regions.

Tyuya Muyun, Ferghana, U.S.S.R. Tyuya Muyun is located about 50 miles east of Ferghana in southeastern Turkistan and is the type locality for the mineral tyuyamunite. The deposit at Tyuya Muyun was first worked in 1904 and supplied nearly all of Russia's production of uranium and radium until the acquisition of Joachimsthal and the nearby deposits of Bohemia and Saxony at the end of World War II. Tyuyamunite was deposited by surface

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waters in a narrow and irregular, but generally cylindrical-shaped, ore body in a highly fractured and highly soluble limestone. The ore body extended vertically downward to a depth of about 500 feet and was estimated by the Russians in 1922 to contain 5,000 tons of ore. Unlike the Grants, New Mexico, deposits in limestone, which are extensive flat-lying deposits with a variety of secondary uranium minerals and minor uraninite, the Tyuya Muyun deposit is limited to a specific vertical fracture zone largely composed of tyuyamunite. The uranium content of about 1 per cent U_3O_8 is several times higher than that of the Grants deposits.

Kara-Tau, Turkistan, U.S.S.R. The Kara-Tau deposits are located in the foothills at the northwest end of the Kara-Tau Range in northeastern Turkistan, about 100 miles north of the town of Turkistan and about 400 miles northwest of Tyuya Muyun. Secondary uranium minerals, principally tyuyamunite and torbernite, occur in bright, greenish-yellow coatings in rock fractures along a narrow band in an old (Cambrian), highly folded, black slate. The principal mineralization in the slate is vanadium, in the form of roscoelite and other black vanadium minerals. The uranium is in scattered irregular pockets in the vanadium-rich band. Other minerals present are calcite, gypsum, barite, quartz, and limonite. The uranium in both the Tyuya Muyun and Kara-Tau deposits is believed to have been deposited by ground waters which removed it from adjacent, very low-grade, uranium-bearing shales similar to the Chattanooga shale.

Red Bluff Deposit, Gila County, Arizona. The Red Bluff deposit is located about 30 miles northwest of Globe, Arizona. The mineralization appears to be largely secondary—carnotite, tyuyamunite, and uranophane—although there are some highly radioactive dark bands and streaks in the ore containing fine-grained uraninite and perhaps other primary minerals. Mineralization is in two favorable beds of a very old (pre-Cambrian) quartzite but is controlled to a large extent by faulting and by the presence of diabase dikes. The deposit was discovered in 1949 and produced several hundred tons of ore in 1952 and 1953.

Silver Cliff Mine, Wyoming. The Silver Cliff Mine is located near Lusk in eastern Wyoming near the Nebraska border. It was discovered about 1879 and during the next few years produced some silver and copper. Uranium was first discovered in 1918, and six carloads of uranium ore, assaying about 3 per cent U_3O_8 , were mined for radium between 1918 and 1922. The next uranium production occurred in 1952. The uranium ore consists primarily of uranophane in fractures in calcite veins or in irregular pockets along a fault in an old (Cambrian) quartzite; torbernite, gummite, and small specimens of pitchblende have also been found. The associated minerals are calcite and limonite, the copper minerals—chalcocite, azurite, malachite, chrysocolla, and cuprite—and native copper and silver.

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This would be classified as a hydrothermal deposit so far as the copper and silver are concerned, even though the present copper and silver minerals are all secondary. Since it contains the primary uranium mineral, pitchblende, perhaps it should be classified so with respect to uranium. However, although the original uranium undoubtedly originated at least in part in the hydrothermal solutions that deposited the silver and copper, the present uranium deposit has formed by oxidation and redeposition of the original primary minerals, perhaps after movement for a considerable distance. There is as yet no indication of substantial primary mineralization in depth as at Marysvale or Urgeirica. The deposit is therefore classed here as an oxidized secondary deposit.

Bukhovo, Bulgaria. The Bukhovo or Goten deposit, about 8 miles northwest of Sofia, Bulgaria, is a small, shallow, lens-shaped deposit of torbernite and autunite, with limonite, in a highly fractured zone in a quartzite-type formation. It has a uranium content about the same as the average carnotite deposit. There is no evidence of a true vein, or of primary minerals, and the uranium is presumed to have been deposited from surface waters which carried it from nearby shales.

Cuneo-Lurisia District, Italy. Another group of deposits of secondary uranium minerals, very similar to the oxidized zones of the Portuguese and Marysvale deposits but which have not yet been proved to have primary mineralization at depth, is located about 60 miles west of Genoa, Italy, in the rugged foothills of the Maritime Alps south and southeast of the towns of Cuneo and Mondovi. The deposits are found along a belt about 15 miles long in moderately old (Permian), highly folded and fractured schists associated with small, irregular quartz-pyrite veins. Heavy weathering has resulted in a good soil cover which obscures much of the bedrock and makes prospecting difficult. The principal uranium minerals are autunite, torbernite, and uranophane, which occur in spotty fashion along the veins and occasionally in the adjacent wall rock, composed largely of thin layers of sericite and quartz. The wall rock also contains some pyrite, chlorite, and a black graphitic material. The rock near the veins is usually stained red or red-brown by limonite and hematite, with considerable alteration of feldspar to clay minerals.

Mt. Painter, South Australia. A small tonnage of secondary uranium ore was mined for its radium content from small pockets in fracture zones at Mt. Painter in the Flinders Ranges about 300 miles north of Adelaide, South Australia, during the period of early production from Radium Hill. Most of the known mineable ore, consisting of autunite and torbernite, was mined out at that time. However, a large mass of crushed red granite gneiss and granite nearby at East Painter Camp contains low-grade secondary mineraliza-

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tion spread throughout a large area and containing local concentrations in small veins and fissures. To date no quantity of mineable ore has been found, but the possibility exists that some may be found by further exploration. Although a few very small grains of uraninite have been identified, the occurrence is at present listed in the category of secondary oxidized deposits with little present indication of important primary mineralization at depth. The secondary minerals are visible only in local concentrations along fractures.

FLUORITE DEPOSITS

Fluorite is a mineral frequently found in uranium deposits, particularly in primary vein deposits, but in several other types as well. This association is reversed in at least one type of fluorite deposit. This type of deposit has not yet been a commercial source of uranium, although there is a possibility that some of these deposits may one day supply a small production. Uranium-bearing fluorite deposits are known in Utah, Nevada, Colorado, Wyoming, New Mexico, and Arizona, generally on the fringes of the Colorado Plateau.

Thomas Range, Utah, Deposits. The Thomas Range fluorite district is located on the west side of the Thomas Range about 100 miles southwest of Salt Lake City, in Juab County, Utah. Fluorite occurs in several deposits in this district, usually in young (Tertiary) granite-like masses that have been intruded into limestone and which it partially replaces. The fluorite is a glassy, dark-blue to purple color when unweathered, but when exposed to weathering becomes white, soft, and clay-like. The uranium occurs as yellow crystals of secondary minerals, principally uranophane, in scattered pockets and fracture coatings adjacent to the fluorite ore bodies, both in the limestone and in the intruded rock, but seldom with the fluorite itself. The deposits are very similar to some of the oxidized secondary deposits so far as the uranium mineralization is concerned, but they are listed separately on the basis of the fluorite association.

DISSEMINATED URANINITE IN METAMORPHOSED CONGLOMERATES

Witwatersrand and Orange Free State Gold Ores. These deposits, underlying large areas of Transvaal and Orange Free State, Union of South Africa, are destined to become one of the world's most important sources of uranium. The first production of uranium occurred in November, 1952, at about the same time as the first production from phosphate deposits in the United States. These deposits, together with the phosphates, provide the only commercial production of uranium from very low-grade sources, each containing usually less than one-half pound of uranium per ton of ore. The Witwatersrand deposits have been among the largest gold producers of the world for many years, and it is only because the huge mining and milling operations are paid

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for primarily by the value of the gold produced that it is possible to recover economically the small uranium content. The deposits of the Orange Free State, which are of the same type, are being intensively developed and promise to be equally important sources of both gold and uranium.

The uranium, in the form of uraninite and perhaps minor amounts of thucolite, occurs with the gold as small grains in relatively thin beds of conglomerate, locally called *reefs*, extending over thousands of square miles. The reefs form part of a thick series of old (pre-Cambrian) quartzites, slates, and conglomerates. Over long periods of time these formations have been subjected to faulting, metamorphism, and intrusion by igneous rocks.

Geologists are in disagreement as to whether the deposits are very old placers or whether they are hydrothermal in origin. They are not the usual hydrothermal vein type of deposit, since they are bedded, nor are they now typically placer deposits, since they are completely solidified and must be mined by the usual underground mining methods at great depths, often several thousand feet below the surface. The ore is composed of very hard, white to smoky quartz pebbles cemented by quartz, sericite, and chlorite, and with dark streaks and seams of pyrite and black carbonaceous material. The gold and uraninite occur in thin seams and between the pebbles in the darker portions of the reefs and can be seen with the naked eye only in the richest specimens.

Blind River District, Ontario, Canada. A new uranium occurrence was discovered in 1953 near Blind River, Ontario, about 60 miles east of Sault Ste. Marie on North Channel, Lake Huron. Uranium occurs intermittently along more than 70 miles of outcrop of several pyritic conglomerate beds at the base of the pre-Cambrian Mississagi quartzite formation. Although the mineralization is not continuous over the entire length of outcrop, large areas are sufficiently uniform in uranium content to make the possibility of large-scale production encouraging.

Uranium occurs in uraninite and brannerite associated with pyrite and a large amount of sericite which gives the rock a greenish cast. Many outcrops are porous and pitted as a result of leaching of the pyrite. There are probably varying amounts of heavy minerals also present and a few, low, gold assays have been obtained. The average uranium content of the better mineralized portions of the conglomerate is in the neighborhood of one-tenth of 1 per cent. Although this is considerably higher than the uranium content of the Rand gold reefs which are very similar, the absence of appreciable gold increases the problem of economic uranium recovery. There is the same problem of origin in the case of these deposits as with the Rand ores. There are many placer characteristics, but also considerable evidence of structural control of mineralization which may indicate hydrothermal deposition.

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DEPOSITS IN OLD LAKE BEDS

A few low-grade deposits of uranium have formed apparently by precipitation of uranium minerals during the process of the drying up of small lakes in arid or semi-arid climates in much the same manner as the formation of many salt deposits. These deposits are called *lacustrine* deposits and belong to the Lindgren classification of deposits formed by "chemical processes of concentration in bodies of surface waters."¹ Only two of these occurrences are worthy of mention: the deposit at Lost Creek near Wamsutter, Wyoming, which has as yet produced no uranium, and the Vinaninkarena, Madagascar, deposits, which have provided small production.

Lost Creek Schroeckingerite Deposit, Wyoming. The Lost Creek deposit is approximately 40 miles north of the town of Wamsutter in Sweetwater County, southern Wyoming. The mineral, schroeckingerite, occurs as small, soft, yellow, rounded pellets up to 1 inch in diameter in sand and clay beds within 2 or 3 feet of the surface. Mineralization favors the clay beds, which are from 2 to 24 inches thick, but is occasionally found in the intervening sandy beds. The deposits are very irregularly distributed over a considerable area, but none has yet been proved economically mineable. No minerals other than schroeckingerite appear to be present. The high degree of solubility of the schroeckingerite results in continual movement and redeposition by surface waters within the clay and sand beds.

Vinaninkarena, Madagascar, Deposits. These deposits near Antsirabé consist of secondary uranium phosphates in peat, clay, and sand in an old lake bed. The deposits are very similar in general character to those at Lost Creek, Wyoming, with uranocircite as the principal mineral instead of schroeckingerite. They have produced small quantities of uranium intermittently for many years.

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¹ By evaporation of solvents—*evaporites*. See Appendix IV.

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VII

THE THORIUM MINERALS

The number of thorium minerals is small compared to the number of uranium minerals, largely because thorium does not form secondary minerals. Although traces of thorium have been found in more than one hundred minerals, only about fourteen are important enough to be mentioned here. All of the thorium minerals may contain some uranium, just as all of the primary uranium minerals may contain some thorium. Varieties of two of the thorium minerals, thorite and thorianite, may contain 20 to 30 per cent or more uranium.

The thorium minerals, like the refractory uranium minerals, occur principally in granite and pegmatites, or in placer deposits derived from these rocks, although within the last few years several vein deposits have been discovered. Thorite and thorianite are the only thorium minerals in which thorium is the major constituent. The other thorium-bearing minerals are rare earth and zirconium minerals which contain thorium as a significant but minor constituent. For example, monazite, xenotime, gadolinite, and allanite contain from 1 to 15 per cent thorium. Unlike uranium, there is only one ore mineral of thorium—monazite—and the thorium extracted from it might be called a double by-product. Monazite itself is usually a by-product (or co-product) of ilmenite, tin, or gold placer mining, and thorium in turn is a by-product of the extraction of rare earths from the monazite.

The prospector's search for thorium is somewhat simplified by the existence of only one ore mineral and three or four potential ore minerals of thorium. He is not hampered by the necessity for evaluating occurrences of secondary minerals that may or may not indicate ore. On the other hand, the thorium minerals are hard to identify in the field, and the prospector may often wish there were secondary thorium minerals to guide him.

Monazite [(Ce,La,Th)PO₄]. Monazite is a phosphate of the rare earths, principally cerium, containing from 1 to 15 per cent thorium oxide¹ and from 0.10 to 1 per cent U₃O₈. It occurs as pink to brown prismatic crystals or angular fragments in granite, gneiss, and pegmatites; but, like other thorium minerals and primary uranium minerals, it is too sparsely scattered throughout

¹ The symbol for thorium oxide is ThO₂, as U₃O₈ is the symbol for uranium oxide. The thorium content equals approximately 88 per cent of the assay expressed in terms of ThO₂.

these rocks to be of commercial interest. However, monazite is concentrated by weathering and erosion processes in commercial quantities in sands and gravels (placer deposits) along rivers and beaches in and near large areas of the primary host rocks. In these deposits monazite typically occurs as small but very distinctive round, glassy grains with brown, reddish-brown, yellowish-brown, yellow, honey-yellow, or green color; yellowish-brown to honey-yellow is the most characteristic. It has a colorless to pale brown or yellowish streak, a resinous luster, a hardness of 5-5.5, and a specific gravity of 4.6-5.3. Monazite has been recovered from placer deposits in India, Brazil, Australia, Malaya, Indonesia, Korea, Ceylon, Formosa, Spain, the U.S.S.R., and the United States. It is also present in small amounts in sands and gravels in many other parts of the world wherever heavy minerals have been concentrated, particularly in Egypt, the Gold Coast, Mozambique, Nigeria, Belgian Congo, New Zealand, Uruguay, Venezuela, and Alaska. In the United States it has been mined in Florida, the Carolinas, and Idaho, and is known in placers in California, Montana, Virginia, and Nevada. In placer deposits, monazite is commonly associated with ilmenite, gold, rutile, zircon, magnetite, cassiterite, garnet, and sometimes the primary uranium minerals.

Recently two new types of deposits have been discovered. Two rich hydrothermal vein deposits containing in places as much as 70 per cent monazite and 5 per cent copper are now known in Cape Province, Union of South Africa, and similar but less rich deposits have been found at Mineral Hill in Lemhi County, Idaho, and at Mountain Pass, California. A conglomerate containing up to 0.5 per cent monazite was also recently discovered in the Big Horn Mountains, Wyoming.

Thorianite (ThO_2 with varying amounts of UO_2 and UO_3). Thorianite is a black to brownish or grayish mineral with a submetallic to greasy luster and a black, gray, or greenish streak. It originally occurs in pegmatites, granite, and gneiss as small cubes which become worn on the edges when subjected to stream or wave action. Its appearance is almost identical to uraninite. It has a hardness of 5-7 and a specific gravity of 9 or above, about the same as pitchblende and uraninite. Thorianite is the richest of the thorium minerals and may contain up to 90 per cent ThO_2 and up to 33 per cent U_3O_8 . The proportions of thorium and uranium are quite variable, but when there is 15 per cent or more U_3O_8 , the mineral is usually called *uranothorianite*. The high uranium varieties are subject to weathering and alteration, sometimes forming coatings similar to gummite and called *thorogummite*.

Thorianite has not been a commercial source of thorium or uranium and is therefore not an ore mineral. However, it has been found in a large number of sand and gravel deposits throughout the world: Ceylon, Madagascar, Siberia, South Island, New Zealand, Alaska, California, and Montana, among others.

THE THORIUM MINERALS

Its principal occurrences are in the gold and tin placers of Alaska, and in Ceylon, Madagascar, and Transbaikalia, Siberia.

Thorite (ThSiO_4). Thorite, thorium silicate, is the second of the two minerals in which thorium is the principal constituent. It can contain up to 80 per cent ThO_2 and, like thorianite, may have uranium replacing thorium (up to 25 per cent U_3O_8). When thorite contains more than 5 per cent U_3O_8 it is usually called *uranothorite*. Thorite occurs in small, square, prismatic crystals with pyramid-like points similar to zircon. It is black, greenish-black, or brown in color, and has a glassy or greasy luster. It has a hardness of 4.5-5, a specific gravity of 4 to 6, and breaks with a clean, glass-like fracture. Thorite occurs in small amounts in granite, granite-like rocks, gneiss, and pegmatites, and in sands and gravels derived from such rocks.

It occurs in beach sands along the coast of South Westland, South Island, New Zealand, and central California, where it is concentrated by wave action into thin, heavy mineral streaks together with magnetite, garnet, ilmenite, and gold, and in the central California gold placers, particularly along the Tuolumne and Consumnes rivers. Among the large number of varieties of thorite found in pegmatites in different parts of the world and given separate names are the following:

Auerlite—Henderson County, North Carolina

Thorogummite, Mackintoshite—Llano County, Texas

Hydrothorite, Nicolayite, Pilbarite, Maitlandite—Wodgina, Western Australia

Calciothorite—Norway

Ferrothorite—Madagascar

Hyblite—Hybla, Ontario

Enalite—Japan

These varieties of thorite are usually altered and have varying amounts of calcium, iron, phosphate, and rare earths substituting for thorium and silica and resulting in yellow, red, and brown colors, less hardness and lower specific gravity than normal thorite.

Several examples of a new type of thorite occurrence in veins have been recently discovered in the Wet Mountains, Custer County, Colorado, in the Powderhorn district near Gunnison, Colorado, at Lemhi Pass, Lemhi County, Idaho, and at Mountain Pass, southern California.

Other Thorium Occurrences.¹ There are no known significant large low-grade deposits of thorium similar to the uranium occurrences in phosphate rock, shale, and lignite. However, thorium has been detected in trace amounts in phosphate beds in Wyoming and in limestones in western Canada. In addi-

¹ Additional thorium minerals are described in Appendix II.

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tion, since nearly all of the thorium minerals are common constituents of granite, it is conceivable that unusually rich thorium-bearing granites may be discovered in the future, although it is unlikely that such a deposit would warrant mining for thorium for many years to come.

SELECTED REFERENCES

See Chapter IV.

VIII

PRODUCTIVE AND OTHER SIGNIFICANT DEPOSITS OF THORIUM

Deposits containing thorium are limited to those of primary minerals, there being no secondary thorium minerals. With the exception of the few recently discovered vein deposits, the sites of original deposition of the thorium minerals—primarily in granite, gneiss, and pegmatites—have provided no significant deposits because the minerals are too widely scattered. However, accumulation of monazite in sands and gravels along streams, rivers, and beaches has resulted in workable placer deposits in many parts of the world and has provided almost all of the world's production of thorium.

Most of the world's past production of monazite has come from Brazil, India, and the United States, although small quantities have been produced in several other countries. Monazite is almost always obtained in conjunction with one or more other valuable minerals, most commonly ilmenite, gold, zircon, or cassiterite (tin stone).

Since 1950, several vein deposits of thorium have been found in the United States and South Africa. The monazite vein at Steenkampskraal, northern Cape Province, discovered in 1950, is already in production and is now a major source of monazite. A second and similar deposit has also been reported in that area. Veins carrying thorite in the Wet Mountains, Custer County, and near Powderhorn, Gunnison County, Colorado, and at Lemhi Pass, Idaho, and monazite-bearing veins at Mineral Pass, near Shoup, Lemhi County, Idaho, were discovered in 1950, 1951, and 1952. Veins containing both monazite and thorite were also discovered in 1950 in the Mountain Pass district, San Bernardino County, California, the site of important rare earths (bastnaesite) deposits. The thorite in the Wet Mountains was deposited by hydrothermal solutions in fractures in granite and gneiss in association with quartz, chalcopyrite, bornite, barite, fluorite, pyrite, hematite, and the rare earth minerals. The mineralization at the other localities is in veins in metamorphic rocks and associated with columbium, other rare earths, and carbonate minerals. These deposits are not now commercial because of the limited demand for thorium, and they are not rich enough in the rare earths to compete with deposits of monazite sand and

bastnaesite.¹ However, were a sizable demand to develop for thorium for atomic energy purposes, these deposits would undoubtedly become of considerable importance.

BRAZIL

During the first half of the present century, Brazil supplied approximately half of the world's production of monazite. About 40 per cent of this production came from the states of Bahia and Rio de Janeiro and the remainder from Espírito Santo. Less important deposits are also known in Paraíba do Norte and Rio Grande do Norte. The richest concentrations of monazite are found along the present beaches, and in a narrow strip of elevated beach bars just inland from the present beaches, along the coastline for a distance of about 400 miles from Barra do Itabapoana, Rio de Janeiro, to Joacema, Bahia.

The largest known Brazilian deposits are those near Barra do Itabapoana, in the northeast corner of Rio de Janeiro; south and north of Vitoria, southern Espírito Santo, from Anchieta to Riacho; and in southern Bahia. Very little is known about the deposits in the northeastern states of Paraíba do Norte and Rio Grande do Norte which, although apparently low in grade, may be quite large.

The richest deposits are long, narrow, and shallow, normally only 10 to 30 feet wide and 6 to 10 feet deep. The heavy-mineral content of the sand ranges from a few per cent to 75 per cent or more, the remainder of the deposit consisting of quartz sand and shell fragments. The heavy-mineral portion usually contains from one-third to three-fourths ilmenite, one-third or less zircon, and from less than 1 per cent to more than 10 per cent monazite, garnet, magnetite, and rutile. The deposits are found on present beaches, on old beach terraces, in elevated sand bars, in delta deposits, or in sand dunes formed from any of these. The bar deposits are the richest and most common.

The deposits can be recognized by the black color of the ilmenite and, in the case of the richer deposits, by the narrow, golden streaks of monazite in the dark heavy-mineral beds. The elevated beach and bar deposits are usually covered by a few feet of white quartz sand and often by vegetation which must be removed or penetrated by shallow drill holes or pits to determine their extent. The black deposits on present beaches can sometimes be seen from the air, although at other times the same deposit will be covered by a thin accumulation of white beach sand. Accumulations of magnetite containing little or no monazite have the same dark appearance and may be misleading without a counter to determine the presence or lack of radioactivity.

Barra do Itabapoana, Rio de Janeiro. The major monazite deposits of the state of Rio de Janeiro extend discontinuously along the coast, and inland

¹ See Appendix II—Other Thorium Minerals.



PLATE XI. Monazite Deposits in elevated bar near Guarapary, Espírito Santo, Brazil.

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about 2 miles, south from Barra do Itabapoana about 15 miles to Guaximatiba. They are considered to be the largest in Brazil. The deposits vary in length from 75 feet to 2 miles and are from 15 to 40 feet wide; their maximum thickness is about 12 feet.

Espírito Santo. The best deposits in Espírito Santo are found between Guarapary and Boa Vista de Siri, about 50 miles to the south, at Lima, Meaipi, Ubahy, Maiba, Ubu, Paraty, Piuma, Caju, and Siri. Other deposits are located north of Guarapary at Ponta da Fructa and for 50 miles along the coast north of Vitoria to Riacho, at Caropebus, Jacaraipé, Capuba, Boa Vista de Nova Almeida, Saué, Sai, and Barra do Riacho. These deposits are mostly long, narrow, elevated bars just back of the present beaches. Smaller and lower-grade deposits are found north of Riacho all the way to the border of Bahia.

Bahia. The monazite deposits in the state of Bahia occur along the coast from Caravellas north about 150 miles to Canavieiras, near Pôrto Alegre, Viçosa, Alcobaça, Prado, Comoxatiba, Trancoso, Pôrto Seguro, and Santa Cruz. They occur mainly along present beaches and are either rich but small, or large and very low in monazite content. However, two good deposits in elevated bars are located at Ponta da Guaratiba near Alcobaça, and at Joacema between Comoxatiba and Trancoso.

States of Rio Grande do Norte and Paraíba. The monazite deposits in these states are large in extent, but low in grade. They occur in dune sands for several miles along the coast near Cunhau, about 30 miles south of Natal, and at Cabadello, the port city of São João Pessoa.

INDIA

During the period from 1911 to 1945, India supplied about two-fifths of the world production of monazite, all from the state of Travancore bordering the southwest coast of India. As in the case of Brazil, the monazite was produced in conjunction with ilmenite. Other minerals present in the deposits are zircon, rutile, sillimanite, kyanite, and quartz. Deposits of monazite are also found in Malabar District, north of Travancore, and on the east coast in Madras and Orissa; these are lower in grade and are not known to have been worked commercially. The Indian deposits are in general similar to those in Brazil, but they favor beaches, dunes, and river deltas rather than elevated bars.

Travancore. The Travancore deposits are found mainly along the beaches in four areas: between Muttum and Puddur, near Kovilam (south of Trivandrum), between Anjengo and Warkalli, and near Chavara. The most important deposits worked to date are a mile-long beach at Manavalakurichi, near Kovalam, and an 11-mile beach near Chavara north of Quilan.

Malabar District, West Coast. Monazite deposits occur along the beaches between Blangad and Ponnani along the Chowghat-Ponnani coast. The sands

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contain 40 to 50 times more ilmenite than monazite, which makes up considerably less than 1 per cent of the sands.

Madras Presidency, East Coast. Low concentrations of monazite occur along the Tinnevely coast in southeast India on the Gulf of Mannaar from Cape Comorin north to Liparum. Other deposits occur at the mouths of the Vaippar and Kallar rivers to the north; farther north on the beaches of Ramnad and Tanjore districts; and along the Golconda coast between the Godavari River delta, Madras, and Chilka Lake, Orissa.

State of Orissa, East Coast. Monazite-bearing beach sands have been reported from the Cuttack District of Orissa, south of Bengal, between the Mayapura, Mohana, and Mahanadi rivers, and near Dowdeswell and False Point.

CEYLON

Ceylon has produced several hundred tons of monazite from beach deposits and a few tons of thorianite from river gravels derived from pegmatites and gneiss. The monazite is associated with ilmenite in the beach sands, as in India and Brazil. Ceylon monazite contains the highest proportion of thorium known, about 10 per cent ThO_2 as compared to about 8 per cent in Indian monazite and about 5 per cent in Brazilian monazite. Deposits on the east coast are situated near river mouths, are very low in monazite, and contain several hundred times as much ilmenite. Deposits on the west coast are higher in grade and more like those of Travancore and Brazil, although smaller.

West Coast Deposits. The best deposits on the west coast of Ceylon are located at Kaikawala Beach, Kudremalai Bay, Marawila Beach, Welaboda, and at the mouths of the Maya Oya, Ginganga, and Kalugana rivers. Some of these deposits have rich streaks and pockets containing up to 10 per cent or more monazite.

East Coast Deposits. The two largest ilmenite deposits containing small amounts of monazite are at Pulmoddai and Tirukkivil. They are reported to contain up to 75 per cent ilmenite, but monazite probably makes up less than $\frac{1}{4}$ per cent of the deposits.

Thorianite Deposits. Small thorianite deposits are fairly widely distributed in the highlands of the interior of Ceylon. Thorianite is recovered during the working of river and stream gravels for gems. The best deposits are reported in the Ratnapura district, south-central Ceylon. Ceylon thorianite contains from 15 to 30 per cent U_3O_8 .

INDONESIA

Indonesia produced about one-tenth of the world's monazite output during 1936-1939 and ranked second in importance after India as a producer for that

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period. The major sources of monazite in Indonesia are the three islands of Singkep, Billiton, and Bangka off the east coast of Sumatra, where it is a by-product of tin (cassiterite) dredging. Most of the reported production has come from Singkep. The three islands are second only to Malaya in the production of tin from placer deposits and represent one of the world's major sources of tin production. Monazite is a minor constituent in these deposits but can be recovered profitably because the cost of mining is chargeable to the tin. Other minerals present are zircon, tourmaline, arsenopyrite, marcasite, ilmenite, and wolframite. The deposits are of three types: stream gravels and old submerged beaches, having the highest monazite content; deposits resulting from the weathering and decay of the granite and pegmatites in which cassiterite and monazite were original components, having a lesser monazite content; and granite and pegmatites, having the lowest monazite content. The thorium content of Indonesian monazite is somewhat less than that of Brazil.

Monazite has also been reported to occur in similar deposits on the beaches of eastern, southern, and southwestern Borneo; in river placers near Bengara, North East Borneo; and in the north coast beach sands of Sumatra.

MALAYA

A few thousand tons of monazite are reported to have been produced from Malayan tin placers between 1942 and 1944. The best monazite-bearing tin deposits are reported in the Unfederated Malay States and the Straits Settlements, which, however, are the poorest tin-producing areas. The thorium content of the monazite appears to be greater than in Brazilian but less than in Indian monazite. The best known tin deposits are in the Federated Malay States at Taiping, Kampar, Malim, Nawar, and Ipoh; along the Perak and Batang rivers in Perak state; and along the Pahang River, Pahang state. The deposits in the Unfederated Malay States are in the states of Perlis, Kedah, Kelantan, and Trengganu, and those in the Straits Settlements at Wellesley and Dindings. The Malayan deposits are mainly inland along river courses rather than along the beaches.

AUSTRALIA

The world's best deposits of zircon occur along the beaches of New South Wales, Queensland, and Western Australia, and Australia has produced small quantities of monazite as a by-product from the Queensland deposits. Monazite occurs with zircon, ilmenite, and rutile for a distance of about 50 miles along the coast of southern Queensland, also extending southward to below Byron Bay, New South Wales, in an elevated beach deposit just above the present water line. Other and similar deposits of monazite occur along the coast of King Island in Bass Strait between Victoria and Tasmania.

PRODUCTIVE AND OTHER SIGNIFICANT DEPOSITS OF THORIUM

UNITED STATES

Commercial or near-commercial concentrations of monazite in stream placers or old beach deposits are known in North and South Carolina, Idaho, and Florida. An old (Cambrian) consolidated fossil placer containing monazite was discovered in 1951 in Wyoming, but has not provided any production to date. The vein deposits in Idaho, California, and Colorado are not presently economic.

The only significant production of monazite prior to 1947, when production began in Florida and Idaho, occurred in the Carolinas between 1893 and 1917. During that period monazite production amounted to approximately 5,000 tons. During the same period a production of a few hundred tons of monazite was achieved as a by-product of gold-dredging in Idaho.

North and South Carolina. Most of the United States production prior to 1917 came from stream gravels in an area approximately 150 miles long by 20 miles wide at the foot of the Blue Ridge Mountains in western North and South Carolina. The deposits worked at that time were small and high-grade, and suitable for hand-mining methods only; they have not been mined since that time. Following World War II, larger but lower-grade deposits were found along tributaries of the Savannah River southeast of Augusta, Georgia, in southern South Carolina, and in old beach bars of Pleistocene and older age along the eastern coastal areas of South Carolina and Georgia. The monazite in the Carolinas is associated with the usual placer minerals, particularly garnet, rutile, ilmenite, zircon, and gold. These minerals are not present in sufficient quantity to have commercial significance, with the occasional exception of gold in the smaller deposits and ilmenite in the larger ones. The thorium content of the monazite is variable, but in general less than in Brazilian monazite.

Idaho. The principal production of monazite in the United States at present comes from stream and river placers along the western edge of a large granite area in central Idaho called the Idaho batholith. As a result of weathering and erosion of the granite, monazite has been concentrated along with gold, ilmenite, magnetite, garnet, rutile, zircon, and in some cases minor quantities of the uranium pegmatite minerals, in valleys and meadows along stream courses. The deposits are usually formed where the streams emerge from steep, narrow canyons on to gentle slopes or broad, flat valleys where the abruptly reduced stream velocity causes the heavy minerals to be dropped.

A small production of monazite was first obtained about 1910 as a by-product of gold dredging in the Boise Basin, about 40 miles northeast of Boise. In recent years, however, larger deposits, now dredged primarily for monazite, have been found about 60 miles to the north in the vicinity of Cascade. Additional deposits have been found still farther north and east around the northern

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PLATE XIII. Thorium Deposits.

end of the batholith extending into Montana. The deposits now worked contain only two or three or even fewer pounds of monazite per yard of gravel and must be worked by large dredges handling thousands of yards of gravel a day to be profitable. The monazite contains somewhat less thorium than that from any other area now in production. In 1953, gold was the only by-product occasion-

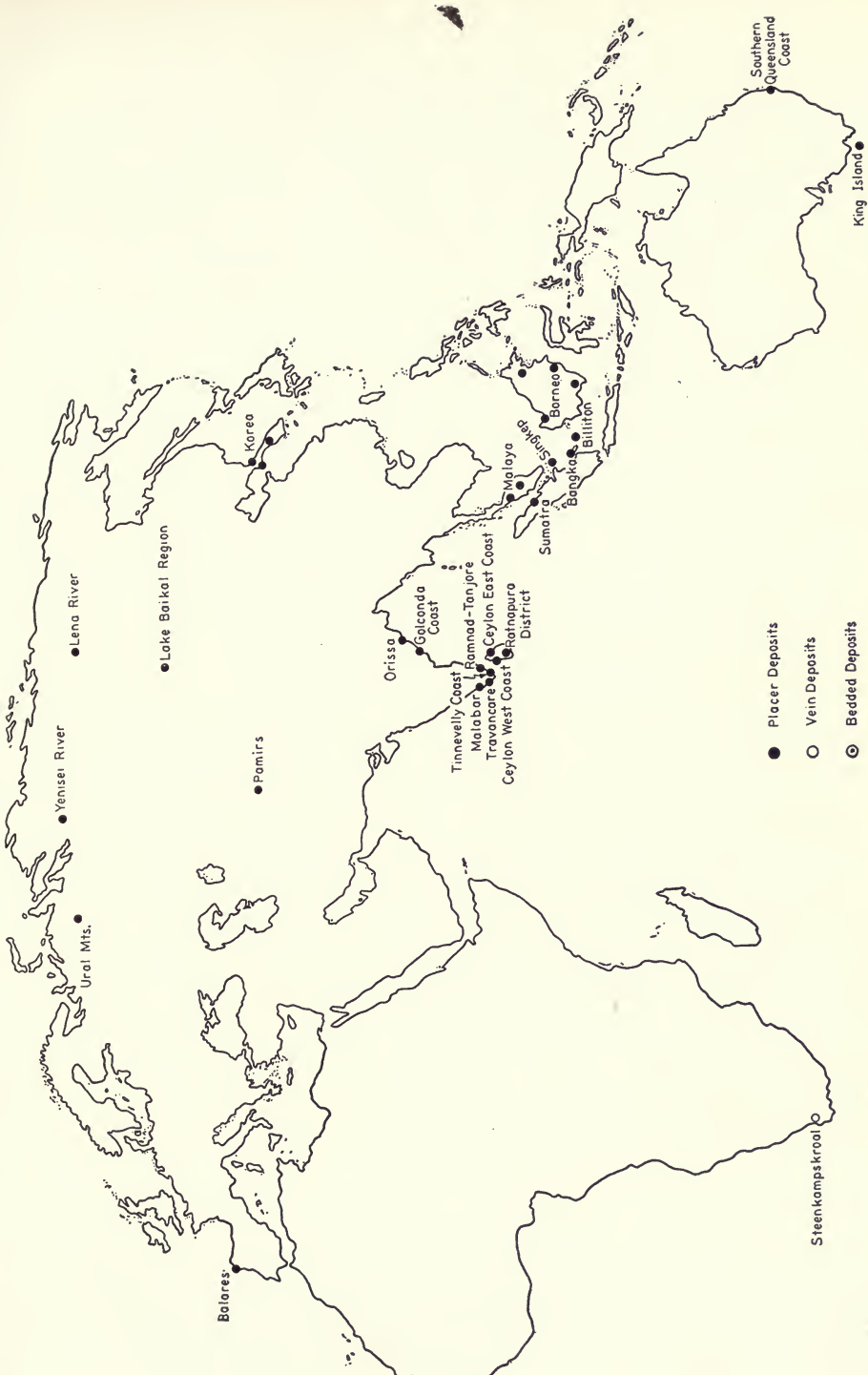


PLATE XIIIB. Thorium Deposits.

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ally commercially recovered, but there were possibilities of economic recovery of some of the other minerals present, including the uranium minerals.

Florida. Since 1949 there has been small but significant production of monazite from one large beach sand operation for ilmenite and rutile at Jacksonville Beach, Florida. This represents the only production of monazite from beach sands in the United States. The thorium content of the Florida monazite is about the same as that from Brazil.

Wyoming. In 1950, a new type of monazite deposit was found at Bald Mountain, 75 miles west of Sheridan, Wyoming, in the northern Big Horn Mountains. It is a very old (Cambrian) conglomerate, several feet thick, at the base of the Deadwood formation of sandstone, shale, and limestone. The conglomerate is brown to light gray in color and is composed of well-rounded pebbles and fine sand. In places it contains several pounds of monazite per ton. It is, in fact, a very old, consolidated fossil placer, similar in some respects to the Witwatersrand gold reefs, formed by erosion of the granite on which it lies and concentration of monazite by stream or wave action several hundred million years ago. The deposit is very similar to present-day placers, except that the sand, gravel, and monazite have been consolidated into rock.

CAPE PROVINCE, UNION OF SOUTH AFRICA

A second, and even more unusual, new type of monazite deposit was discovered in 1950 at Steenkampskraal, 50 miles north of Van Rhynsdorp in north-western Cape Province, Union of South Africa, about 200 miles from Capetown. The deposit is a hydrothermal vein of fine-grained quartz and monazite in very old (pre-Cambrian) granite-type rocks in a semi-desert area of broad flats and small hills. The monazite-quartz vein is exposed over several hundred feet and varies in width from a few inches to more than a foot. Much of the vein is stained by hematite and secondary copper minerals, and the quartz and feldspar in the wall rock along the vein are respectively smoky and reddened. Monazite is also found in the wall rock several inches out from the vein. Pieces of monazite weighing up to several pounds have been found scattered for some distance from the vein along the tops of the small hills.

OTHER PRODUCING COUNTRIES

Some monazite has been produced in Korea from stream and river placer deposits both north and south of the 38th parallel, as a by-product of gold dredging. Beach deposits have also been reported along the northeast coast. A very small production has also come from the beaches at the extreme north-west corner of Spain. Monazite is undoubtedly recovered as a by-product of extensive Russian gold-dredging in several important gold-producing areas in the northern Ural Mountains, in the Pamirs south of Tyuya Muyun, in the Lake Baikal region, and along the Yenisei and Lena rivers of central Siberia.

VIII

THE BERYLLIUM MINERALS

Beryllium has been identified in more than 50 different minerals, in about 30 of which it is a regular constituent making up at least 1 per cent of the mineral. However, like the thorium minerals, only one of the beryllium minerals, beryl, has been found in sufficient quantities and in rich enough concentrations to qualify as an ore mineral. The remaining minerals are either too rare or contain such small amounts of beryllium that they are not economic sources of beryllium. Also, as in the case of thorium, there are no secondary beryllium minerals.

Only a very few of the beryllium minerals are worthy of mention here. The others are so rare that they will only infrequently be encountered even by the mineralogist or mineral collector. One mineral—gadolinite—contains appreciable beryllium but is described in Appendix II as a thorium mineral because of its thorium content. Five uranium minerals: euxenite, fergusonite, samarskite, microlite, and tantalite, contain traces of beryllium, as do two other thorium minerals: thorite and allanite.

The beryllium minerals have three principal types of occurrence: pegmatites, the only present commercial source of beryllium; low-grade deposits in granite and granite-like rocks; and contact metamorphic (*skarn*) deposits.¹ Small amounts of beryllium have also been found in quartz veins. Unlike the primary uranium minerals and the thorium minerals, only a very few of which contain uranium or thorium as a major constituent, 23 of the beryllium minerals contain 10 per cent or more beryllium oxide (BeO). The beryllium minerals are noted for being light in weight and very hard.

Beryl [$\text{Be}_3\text{Al}_2(\text{SiO}_3)_6$; 14% BeO]. Beryl has been found in commercial quantities only in pegmatites and is the only mineral described in this book that is produced commercially from that source, although all of the thorium minerals, all of the primary uranium minerals, and more than half of the beryllium minerals are known to occur in pegmatites.

Beryl occurs in very distinctive hexagonal crystals, some of which have been known to weigh several tons. Its most common color is green, but it may be blue, pink, yellow, or white; it has a white streak. Beryl is very light (specific

¹ Limestones that have been altered and mineralized near a contact with a molten igneous rock.

gravity, 2.7) and is one of the hardest minerals (7.5-8), about as hard as topaz and softer only than corundum and diamond. Its hardness and its glassy appearance (the purer crystals are nearly transparent) result in the gem quality of certain varieties. Emerald is a green beryl and aquamarine is a blue-green beryl. Beryl is found in at least small amounts in nearly every area of the world in which pegmatite deposits are common. It is associated with the typical pegmatite minerals and is usually mined together with mica, feldspar, columbite, tantalite, or spodumene.

Beryl also occurs as small, widely scattered crystals in several granite formations—two such deposits recently discovered near Hillside, Arizona, and in the Sheep Rock Mountains, Utah, give promise of furnishing the first commercial production from that source—and in quartz-tungsten veins as in the Victoria Mountains, New Mexico. The emerald is an exception to the normal beryl occurrence, occurring in bituminous limestone in Columbia and in mica schist in the Ural Mountains, U.S.S.R.

Unlike the primary uranium minerals and the thorium minerals, beryl is not known to occur in appreciable quantities in placer deposits, although a few such occurrences have been reported.

Helvite [$3(\text{Mn,Fe,Zn})\text{BeSiO}_4 \cdot \text{MnS}$; 10-15% BeO]. Helvite is an uncommon mineral occurring in certain vein deposits, pegmatites, and gneisses, but is most noted for its occurrence in garnet-bearing contact metamorphic deposits in limestone such as those near Iron Mountain, New Mexico, where it occurs in quantities which may eventually prove economic. Helvite occurs in four-sided crystals or round masses, yellow, yellow-brown, green, or red-brown in color, with a glassy luster, a colorless streak, a hardness of 6-6.5, and a specific gravity of 3.3. It has also been reported in the U.S.S.R., Saxony, Norway; in Amelia County, Virginia; and in limestone in the Victoria Mountains, Luna County, New Mexico. A variety of helvite—*danalite*—occurs in granite at Cape Ann, Massachusetts, in an iron (magnetite) deposit at Bartlett, New Hampshire, and near Colorado Springs, Colorado.

Chrysoberyl (BeAl_2O_4 ; 20% BeO). Chrysoberyl occurs in tabular crystals, usually in varying shades of green, and has a colorless streak. It is transparent and brittle with a hardness of 8.5 and a specific gravity of 3.75. It occurs in certain pegmatites and mica schists in Germany; in the Ural Mountains, U.S.S.R.; at Lake Como, Italy; and in Norway, Ireland and Brazil. In the United States it occurs at a number of pegmatite localities in Maine; at Had-dam, Connecticut; Orange Summit, New Hampshire; near Saratoga, New York; and near Golden, Colorado. It has also been found in the Manhattan schist, Washington Heights, New York City. Chrysoberyl also occurs in placer deposits with diamond, corundum, garnet, and cassiterite in the U.S.S.R., Southern

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Rhodesia, Belgian Congo, Gold Coast, Japan, Ceylon, Burma, and Western Australia.

Beryllonite (NaBePO_4 ; 20% BeO). Beryllonite, a phosphate of sodium and beryllium, is a rare mineral that occurs in small amounts in pegmatites. It forms short, prismatic to tabular crystals, colorless to white or pale yellow, with a glassy or sometimes pearly luster. It has a hardness of 5.5-6 and a specific gravity of 2.8. Beryllonite has been found at Stoneham and Newry, Oxford County, Maine.

Phenacite (Be_2SiO_4 ; 40% BeO). Phenacite is a rather common mineral in pegmatites, but it is nearly always present in very small amounts. It usually occurs as glassy, colorless, flattish, rhombohedral or prismatic crystals. It is very brittle, has a hardness of 7.5-8 (same as beryl), and a specific gravity of 3. It is occasionally bright yellow, pale rose-red, or brown. The best crystals of phenacite have come from Minas Gerais, Brazil. It is also known in Oxford County, Maine, and El Paso County, Colorado, as well as in the U.S.S.R., France, Tanganyika, Switzerland, and Norway.

Common Minerals Containing Beryllium. Among the well-known minerals that contain traces up to 1 per cent beryllium oxide, other than the uranium and thorium minerals already mentioned, are cassiterite (SnO_2), fluorite (CaF_2), wavellite [$\text{Al}_6(\text{PO}_4)_4(\text{OH},\text{F})_6 \cdot 9\text{H}_2\text{O}$], garnet [$\text{Ca}_3(\text{Al},\text{Fe})_2\text{Si}_3\text{O}_{12}$], vesuvianite (calcium aluminum silicate), nepheline (NaAlSiO_4), tourmaline, and the micas.

Other Beryllium Occurrences. In addition to its occurrence in granite, pegmatites, quartz veins, and contact metamorphic deposits, the element beryllium in unidentified form occurs in very small quantities in bauxite deposits, in clays, and in the ash of certain coals.

SELECTED REFERENCES

See Chapter IV

IX

PRODUCTIVE AND OTHER SIGNIFICANT DEPOSITS OF BERYLLIUM

The only sources of beryllium, like those of thorium, are deposits of primary minerals, and only beryl forms commercial deposits. Unlike the thorium minerals, found mainly in placer deposits, beryl is found in appreciable quantities only at its original place of deposition, in pegmatites, and in less rich deposits in granite or granite-like rocks. However, since both monazite and beryl favor granitic rocks, they are frequently found in the same general areas.

BRAZIL

Brazil has been the largest single producer of beryl, as well as of monazite. The three principal beryl-producing areas of Brazil are the Rio Doce valley and adjacent areas in the state of Minas Gerais, northwest of the port city of Vitoria; the Campina Grande district in the states of Paraíba and Rio Grande do Norte, southwest of Natal; and the Cristais-Berilandia district in the state of Ceará, south of the port city of Fortaleza. In each of these areas there are hundreds of pegmatites, some rich in beryl and others with only moderate amounts or none at all. Because of their greater resistance to erosion, the pegmatites frequently stand out as small ridges or knolls above the surrounding countryside. This is particularly true in the relatively flat country of the two northern districts of Campina Grande and Cristais-Berilandia.

The pegmatites vary in size and shape, but normally they do not exceed several hundred yards in length and one or two hundred feet in width. They are usually vertical or inclined at a steep angle and may extend in depth to several times their width. Beryl is usually found in zones occupying only certain parts of the pegmatite. The beryl in the richer zones is easily separated from the quartz, mica, feldspar, and the less common pegmatite minerals by hand mining with pick and shovel or by blasting and sorting the broken rock. Many of the pegmatites in Minas Gerais have small quantities of uranium minerals which are sometimes sorted out along with the beryl and other minerals, although in that area beryl is the principal product. In the Campina Grande district the pegmatites have tantalite and columbite in the ratio of

PRODUCTIVE AND OTHER SIGNIFICANT DEPOSITS OF BERYLLIUM

about 1 to 10 of beryl, and beryl production is often dependent upon a market for those minerals.

INDIA

India has been the second largest producer of beryl since it was first mined in the early 1930's. Beryl pegmatites are widely distributed in India, but the major deposits are in Rajputana, Bihar, and Madras.

Rajputana. Most of the beryl production in India has come from Rajputana province in the northwest corner of the country in the vicinity of the cities of Jaipur, Ajmer, and Udaipur. The Rajputana pegmatites are seldom more than 100 feet long, smaller than those of Bihar and Madras and those of Brazil. Minerals present, in order of abundance, are feldspar, quartz, beryl, mica, tourmaline, and garnet. Mining is almost always by hand methods. The Bisundi mine, one of the northernmost of the major Rajputana pegmatites, is an exception to the normal size, being more than 1,000 feet long and in places more than 100 feet wide. A second unusually large pegmatite is the site of the Eklinpura mine, about 60 miles southwest of the Bisundi. This pegmatite is nearly 1,600 feet long and 150 feet wide.

Most of the Rajputana deposits have produced primarily beryl, although mica was an important product of the Jamoli mine, 12 miles southeast of the Bisundi mine, and columbite and tantalite have been the principal products of the Lakhola mine in the southern part of the beryl district.

Bihar. The pegmatites of central Bihar in the northeast corner of India have been important mica producers, and some beryl has been mined as a by-product. However, the pegmatites are generally poor in beryl, and the production possibilities are poorer than in Rajputana.

Madras. The pegmatites of Madras occur in the same granitic rocks that provide the monazite for the Travancore and Madras monazite deposits. They are principally mica mines, but some beryl is also produced. The most important deposits are reported in the Nellore district on the east-central coast north of the city of Madras.

ARGENTINA

The major beryl deposits of Argentina are located in the provinces of Cordoba and San Luis in Central Argentina. Minor deposits occur in La Rioja and Catamarca provinces in the northwest. The Las Tapias mine in Cordoba, 9 miles northeast of Villa Dolores, has been the largest beryl producer and has supplied most of the Argentine production. The deposit is an irregularly shaped pegmatite in a mica-rich granite-like rock. The pegmatite contained one continuous zone of massive beryl, now mined out, 200 feet long and 130 feet wide with an

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average thickness of nearly 3 feet. The Las Tapias pegmatite is believed to have been the most productive single deposit in the world.

SOUTH AFRICA

Production of beryl in South Africa has increased rapidly since World War II, and this area is now probably the largest producer after Brazil. The beryl pegmatites are located in the Bikita area of Southern Rhodesia; in Namaqualand, northwest Cape Province, Union of South Africa, and in the adjacent Warmbad district of southern Southwest Africa; and in the Karibib district of central Southwest Africa.

UNITED STATES

The United States now ranks fourth in the production of beryl after Brazil, Argentina, and South Africa, but produces only a few hundred tons annually. Beryl is usually recovered in the United States as a by-product of the mining of pegmatites for other materials, primarily feldspar, mica, and spodumene (lithium ore). The beryl pegmatites in the United States are less common than in Brazil and India, and, with a very few exceptions, smaller and less rich in beryl. In addition to pegmatites, low-grade beryl deposits in granite and a deposit of helvite are potential sources of beryllium in the United States.

Pegmatite Deposits. The principal beryl production in the United States has come from pegmatites in the Keystone and Custer districts of the southern Black Hills, South Dakota; in New England; and in Colorado. The Sitting Bull, Ingersoll, Peerless, Hugo, and adjacent mines near Keystone, and the Helen Beryl, Bull Moose, and Beecher Lode deposits near Custer have been the biggest producers. The best deposits in New England are at Newry Hill and Red Hill, Oxford County, Maine; in the Middletown district, Connecticut; and at West Rumney, Grafton County, and Beryl Mountain, Sullivan County, New Hampshire. The largest deposits of beryl in Colorado are the Hyatt, Big Boulder, and Buckhorn pegmatites in the Crystal Mountain district, Larimer County, and the Bucky pegmatite, Quartz Creek district, Gunnison County.

Less important deposits of beryl are known in pegmatites in New Mexico, Idaho, Massachusetts, New York, North Carolina, Virginia, Arizona, Wyoming, California, and Nevada. The best known of these are the Harding mine, Taos County, New Mexico, and the Muscovite mine, Latah County, Idaho. The pegmatites at Kings Mountain, North Carolina have large zones of fine-grained beryl mixed with other minerals, principally spodumene, that may eventually provide substantial production if a milling process for separating out the beryl can be developed.

Granite Deposits. The two potentially productive low-grade deposits of beryl in granite are near Hillside, Arizona, and in the Sheep Rock Mountains

PRODUCTIVE AND OTHER SIGNIFICANT DEPOSITS OF BERYLLIUM



PLATE XIII A. Peerless Mine near Keystone, South Dakota, mined for beryl, feldspar and mica. *Courtesy D. H. Hershberger, Brush Beryllium Co.*



PLATE XIII B. Kings Mountain, North Carolina. Open-pit Pegmatite Mining. *Courtesy Foote Mineral Co.*

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PLATE XIV. Beryllium Deposits.

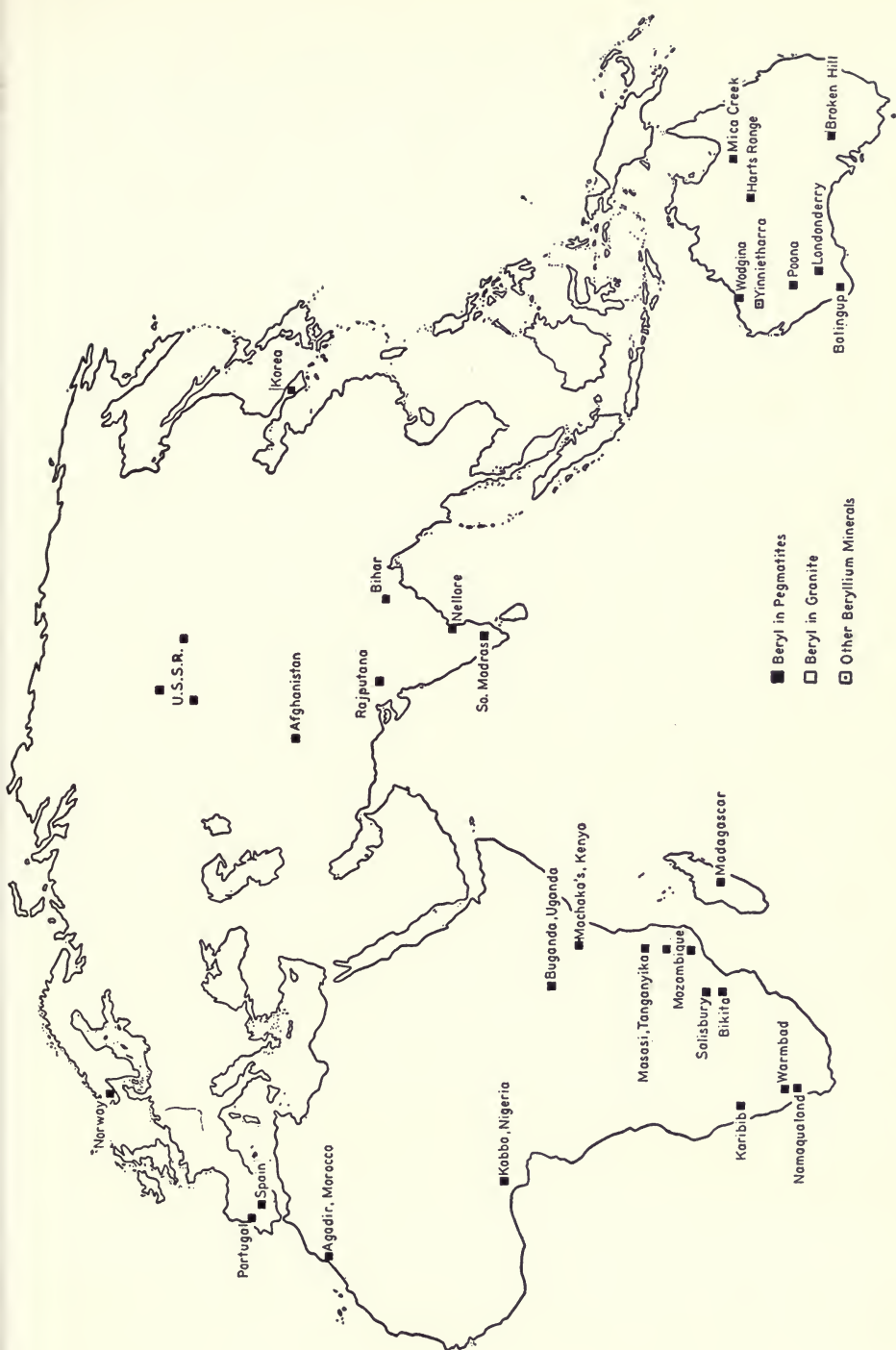


PLATE XIVB. Beryllium Deposits.

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60 miles northwest of Eureka, Utah. Beryl occurs mainly in very small, light-colored crystals that cannot be seen with the naked eye, and occasionally as concentrations of larger crystals and radiating clusters as large as a foot in diameter, usually associated with fracture zones in the granite. The beryl is found only in the white portions of an otherwise reddish-colored granite. Some of these white areas are several hundred feet in diameter. Although the average beryl content is considerably lower in this type of deposit than in the mineable zones of pegmatites, the volume of beryl-containing rock is many times larger and will permit large-scale mining methods. The problem of recovering the beryl from the rock once it is mined is similar to that encountered at Kings Mountain.

Iron Mountain, New Mexico, Helvite Deposits. Deposits of beryllium and tungsten have been found in the Iron Mountain district in northwestern Sierra County and southwestern Socorro County, New Mexico. They are known as *contact-metamorphic* deposits because they have been formed by alteration and mineralization of limestone and shale by the intrusion of molten igneous masses of granite and volcanic rocks. The limestone and shale near the intrusive contact have been transformed into an iron- and silica-rich rock containing various minerals, including the beryllium silicate, helvite, and the tungsten minerals, scheelite, and powellite. The deposits are irregular in shape and the beryllium and tungsten minerals occur in bands or layers which have given rise to the name *ribbon rock*. The mineralization is also found in some places as thick pods and pipe-like masses in fractures and crushed zones.

Although the principal beryllium mineral is helvite, beryllium also occurs as a minor constituent in the minerals grossularite (a variety of garnet), idocrase, and chlorite. The other principal minerals in the deposits are magnetite, hematite, and fluorite; green mica, sericite, and chlorite are also present in local concentrations. As would be expected from the minerals present, the altered rock in which the deposits are located is dark green to black in color. Although there is a large tonnage of beryllium-bearing rock at Iron Mountain, the low grade of the deposits and the difficulty of extracting the beryllium from the rock has prevented mining. It is possible, nevertheless, that these deposits or similar but higher-grade deposits, if found, may become commercial sources of beryllium.

OTHER PRODUCING COUNTRIES

In addition to the major beryl-producing countries mentioned above, beryl has been produced from pegmatites in Australia, Canada, Kenya, Korea, Madagascar, Morocco, Mozambique, Nigeria, Portugal, Spain, Uganda, U.S.S.R.

PART TWO

WHERE TO LOOK:

EVALUATION OF VARIOUS AREAS OF THE WORLD

X

INTRODUCTION

The question most frequently asked of the Atomic Energy Commission's Division of Raw Materials is "Where do I look?" or "Where should I go to have the best chance of finding a valuable deposit of uranium, thorium, or beryllium?" There is, of course, no easy answer to that question, any more than there is an easy answer to where to look for copper, lead, gold, or any other metal. "Gold is where you find it" is still the only safe and sure rule for prospecting for any mineral, and the minerals for atomic energy are no exception. The Commission has tried to expand upon this a little with respect to uranium by stating that "Prospecting for uranium will probably be most successful if carried on in areas where: (1) uranium has been found before, (2) the geologic conditions are similar to those existing where uranium has been found before, or (3) other metals have been found (especially lead, zinc, cobalt, copper, silver, nickel, bismuth, and vanadium)." ¹

This type of information might not appear to be particularly helpful until one is reminded that there are always good reasons for any mineral deposit being where it is, even though they may not be evident even to the expert. These reasons have to do with the geologic conditions existing at that particular place. Certain of these conditions may favor one metal, while other more general conditions may result in the formation of deposits of a wide variety of metals. Although it is the job of geologists, and of the prospector, to try to determine what the favorable geologic conditions for a given metal are and where such conditions might exist in the world, both must begin their jobs with the known deposits. In addition to providing important information about where else to look, known deposits are the visible proof of the geologic conditions sought, and within their immediate vicinities are located probably the best hunting grounds for new deposits.

Thus the student or mineral collector will go to some of the numerous localities listed in the descriptions of the various minerals, and the prospector will go to areas in which known ore deposits occur. In either case, success is more likely by this method than by any other; and even though hundreds of pros-

¹ *Prospecting for Uranium*, U.S.A.E.C. and U.S.G.S., U. S. Govt. Printing Office, 1949. (Revised October 1951).

pectors have gone before, some of the best deposits may have been overlooked. This is because of a very important and fundamental concept: The concept of *metallogenic provinces*.

Metallogenic provinces are areas of the earth's surface in which deposits of the minerals of particular metals are much more abundant than in other areas. The ore deposits of the world are not evenly distributed, but are grouped together in various localities scattered over the world. The distribution of the great mining centers of the world, as shown in any commercial atlas, will prove this at a glance. Furthermore, all or even most of the metals are not represented in any one mining district. In any single locality, only one or a few of the metals predominate, and that area is a metallogenic province of that metal or metals. For instance, Arizona and the Northern Rhodesia-Congo border area are copper provinces; the Tri-State district of Oklahoma, Kansas, and Missouri is a lead-zinc province; and Transvaal and the Orange Free State in the Union of South Africa form a gold province. These areas and numerous other metallogenic provinces in the world are good hunting grounds for particular metals.

Most of the important known deposits of uranium, thorium, and beryllium occur in similar metallogenic provinces. The greatest of the uranium provinces are the southern Congo-Northern Rhodesia border region (coinciding with the copper province), the Great Bear Lake and Lake Athabaska areas of Canada, and the Colorado Plateau area of the United States. Many other uranium provinces, apparently less productive, but nonetheless worthy of consideration, are indicated by the variety of localities in which the deposits described in the preceding chapters occur. The greatest thorium and beryllium provinces are in Brazil and India, with less important provinces in many other countries.

A second geologic concept comparable to that of metallogenic provinces, but somewhat less definite and perhaps less important except to the professional prospector or geologist, has to do with the variation in metals deposited in the earth's crust at different periods in geologic time. Certain periods in the earth's history have apparently been especially favorable for the deposition of certain metals, and these are referred to as *metallogenic epochs*. As we have seen, the most important primary uranium deposits occur in very old rocks belonging to the broad period of time referred to by geologists as pre-Cambrian, and it is presumed that the formation of the deposits in most cases also occurred during that period. On the other hand, the deposits of the Colorado Plateau and the primary vein deposits of Portugal are believed to be of Mesozoic, or medium, age.¹ The deposits of Marysvale, Utah, and the Boulder, Montana, area are of Tertiary age, or relatively young. Nearly all

¹ Or slightly older in the case of Portugal.

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uranium deposits belong to one of these three metallogenic epochs. Although the theory of metallogenic epochs is based on some very good evidence and undoubtedly has some application to uranium, it would be unwise to exclude certain areas in prospecting just because the age of the mineralization in that area did not belong to one of these periods. Metallogenic epochs are not so apparent with respect to thorium and beryllium.

There is one more clue of a general nature that will be helpful particularly to those who have only an avocational interest in prospecting for uranium, thorium, and beryllium and who have neither the inclination nor the time and money to seek out the specific geologically favorable areas on the basis of scientific evidence. These minerals are almost always found in association with minerals of other metals. Therefore, any place where metal deposits have been found is usually worth consideration, even though the metals sought have not been reported there. This is more true of uranium than of thorium and beryllium which are much more restricted in their type of occurrence. This method of defining favorable prospecting areas must, of course, be used with discretion, always keeping in mind those particular minerals with which uranium, thorium, and beryllium are most often associated.

With the above points in mind one can now attempt to define the possibilities of broad, generally favorable areas of the earth. Within these broad areas, the localities that meet the more specific geologic requirements based on information developed from the study of known deposits, or from which uranium, thorium, or beryllium have been reported, will, in most cases, have definite advantages.

XII

SHIELD AREAS OF THE WORLD

The most important known primary vein deposits of uranium, those responsible for the greatest production to date as well as the several promising future producers, are all found in large areas of the earth's surface known as *shields*. The exact nature and meaning of this relation are not well understood, but the relation does exist and is an important factor which must be taken into account in any attempt to outline favorable areas for uranium.

Shields are large, broad regions, several hundred miles across. They are composed primarily of very old (pre-Cambrian) rocks which, over hundreds of millions of years, have reached a state of static equilibrium; that is, they have not been affected by great mountain building and earth movement for a long time and their surfaces are relatively low and even, without spectacular topographic variations. A shield may be nearly flat with occasional low-lying ridges, or rugged and hilly, but does not usually have major mountain ranges. Shields may be thought of as the eroded remnants or roots of ancient mountain systems.

Before the shield areas were finally stabilized, the rocks were subjected to extensive folding, faulting, mountain building, and intrusion of other rock masses from below, all of which resulted in changes in the original rock formations to form new rock types. The most prevalent formations are schists, gneisses, quartzites, slates, dolomites, and other metamorphic rocks and granite and granite-like rocks, all favorable host or source rocks for uranium.

The important primary uranium deposits have been found along the edges of these shields and it is thought, therefore, that the shield borders may be especially favorable. Pegmatites containing beryl, as well as those having uranium minerals, also appear to favor the edges of shields, but there is some evidence that important primary vein deposits of uranium are not likely to be encountered in those localities along the shield borders where pegmatites are numerous. Although monazite and other thorium minerals are common as minor constituents in granitic rocks in all shield areas, the possibility of their concentration into placer deposits is improved by rapid weathering and erosion such as occurs in the shields of the tropics and subtropics.

SHIELD AREAS OF THE WORLD

CANADIAN SHIELD

The Canadian Shield is the only shield area on the North American continent. Because of the relation between the major primary vein deposits of uranium and shield areas, it is the best prospecting ground available to North Americans for deposits like those at Great Bear Lake and Shinkolobwe. The Canadian Shield occupies the entire eastern two-thirds of Canada, and the same structure extends across the southern two-thirds of Greenland.

Up to late 1953, samples containing 0.05% or more uranium or thorium had been reported from about 645 different properties in Canada. More than 90 per cent of these properties are within the Canadian Shield, primarily along the western and southern edges, in a zone in places less than 100 miles wide. This zone extends southeast from the east side of Great Bear Lake past Great Slave Lake and Lake Athabaska to Lac la Ronge in central Saskatchewan, east through Flin Flon on the Saskatchewan-Manitoba border, south to the Minnesota border at Lake of the Woods, and east along the north shore of the Great Lakes to Ontario and Quebec. Of the reported occurrences about half were in pegmatites and the other half were veins or mineralized zones of pitchblende. There were a few thorium occurrences none of which appeared to be of commercial interest.

The best pitchblende deposits have been found along the northwestern edge of the shield; whereas the southeastern edge has the largest number of pegmatites. South and east of Flin Flon the pitchblende deposits change in character and are associated primarily with dark, heavy, iron-rich dikes, most of them too small to be of economic importance. However, the discovery in 1953 of extensive uranium mineralization in conglomerate in the Blind River district, east of Sault Ste. Marie, increases the attractiveness of the south edge of the shield for uranium. Some beryl occurs in southern Manitoba, Ontario, and Quebec, and it has been reported in the vicinity of Yellowknife, Northwest Territories; none of these occurrences has yielded significant production.

Uranium has not been found associated with the gold ores in the gold-producing districts of Yellowknife and Goldfields, although these districts are located in the most favorable portion of the shield border zone. The important copper, cobalt, nickel, and gold mining districts at Copper Cliff, Sudbury, Cobalt, and Kirkland Lake, Ontario, in the area north of Georgian Bay are also apparently barren of uranium, as are the Allard Lake, Quebec, titanium deposits and the Newfoundland and Labrador iron ores.

Geologists are not certain whether the concentration of known uranium occurrences along the border of the Canadian Shield is due to geologic favorability or merely to the fact that this border area has been the most accessible to prospectors. There is reason to believe, however, that the shield border repre-

sents a true uranium province. In any event, whether for reasons of geology or accessibility, this region is certainly the most attractive for prospecting. There is also considerable evidence that the northwestern edge will continue to be the most important part of this province. Prospectors will eventually explore the center of the shield and find the answer to this question; in the meantime, uranium production for a good many years to come will be derived from the shield edge. The prospector, even in much of this area, must be prepared for a rugged life and long periods away from civilization. Furthermore, his prospecting year is restricted to the few months between the ice "break up" in late spring and the "freeze up" in early fall. However, Canada is otherwise one of the best countries for prospectors. Its laws permit prospecting, exploration, and staking of claims on public land in much the same manner as in the United States.

Within the favorable area, the prospector should look for local conditions similar to those existing at known deposits. In the Canadian Shield the rock structures are more important than the type of rock. Although primary uranium mineralization in this area, as well as elsewhere in the world, is believed to be genetically related to granitic rocks, in many places in the Lake Athabaska area and in the areas to the southeast, pitchblende has been deposited in the dark colored *basic* rocks of high iron and high magnesium content. It is, therefore, more important to look for faults, for zones of shearing and fracturing, and for contacts between two rock formations than for a particular rock type.

Little is known of the northern and eastern borders of the Canadian Shield and no significant occurrences of atomic energy minerals have been reported there. Pegmatites are known to exist in Baffinland and on the west coast of Greenland, perhaps making those areas less favorable. The northern border of the shield across northern Canada and Greenland and the east coast of Greenland may warrant investigation. The exploration of this extremely remote area will be slow, but at least until it is much better known than at present it will be a potentially favorable area for prospecting.

The southern edge of the Canadian Shield extends from the Lake of the Woods in Manitoba across northeastern Minnesota, northern Wisconsin, and the upper Michigan peninsula, providing the only shield area in the United States. A monazite-rich quartzite has been found in Marquette County, Michigan; thorogummite is known in the Wausau area, Marathon County, Wisconsin; and primary uranium minerals have been found at several places in the slates and iron formations of the iron ore country. Most of the uranium occurrences are small and very low in grade, but a few small veins of pitchblende approaching economic grade have been found in some of the Michigan iron mines.

SHIELD AREAS OF THE WORLD

The southern extremity of the shield should not yet be excluded as the possible location of important primary deposits. It is also a favorable prospecting ground for deposits like those at Blind River, since formations equivalent to the Mississagi quartzite occur there.

SOUTH AFRICAN SHIELD

The Shinkolobwe mine, the richest known deposit of uranium, is located near Jadotville, Belgian Congo, on the northern border of the South African Shield which includes most of South Africa between the Congo and Cape Province. Along its northern border lies the rich Congo-Rhodesian copper belt extending from the most southeastern extension of the Congo to the border of Angola. Some of the copper mines in this belt are known to have occurrences of uraninite, at least one of which may be mineable. This entire area along the Congo-Rhodesian border is a favorable prospecting ground, for it has both the high-grade pitchblende lodes and the lower-grade copper sulfide and uraninite deposits in slates.

Several occurrences of high-grade pitchblende ore, of which little is yet known, have been found on the Congo side of the border westward from Jadotville, and the host rocks and structures favorable for copper and uranium extend farther west in to Angola. Along this northern border of the shield, both the type of rock and the local structures have probably influenced uranium deposition. Highly folded and fractured quartzites, dolomites, and slates seem to be the best host rocks, and the spectacular color of the secondary copper and uranium minerals in the tropically weathered outcrops of mineralized zones is the principal surface guide to ore.

The uraninite-bearing gold reefs of the Transvaal and Orange Free State, Union of South Africa, lie along the southeast border of the shield, but the unusual nature of these deposits, and the controversy as to their origin, obscure the significance, if any, of this relationship.

The South African Shield provides good prospecting ground for thorium and beryllium, as well as for uranium. On the eastern border of the shield, a relatively new area of beryl-bearing pegmatites is being rapidly developed in the Bikita district of central-east Southern Rhodesia and southward to northeastern Transvaal. Some beryl production comes also from pegmatites near Salisbury and in western and northern Mozambique at the northeast border of the shield. The beryl-producing districts of Namaqualand, Bushmanland, and Gordonia in northwestern Cape Province, and of Warmbad and Karibib in Southwest Africa are located along the southwestern edge of the shield. Undoubtedly, good prospecting ground for beryl all along the east, south, and west sides of the shield is still far from completely explored. The important new monazite vein deposit at Van Rhynsdorp along the extreme southwest

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shield border adds to this area the possibility of new thorium resources. The Mozambique pegmatites contain uraninite as well as samarskite, euxenite, and other refractory uranium minerals, but apparently not in commercial quantities. The davidite deposits of the Tete district, Mozambique, are also in this general locality. Further exploration of this northeast border of the shield might disclose other and more important deposits of uranium.

As in the Canadian Shield, uranium, thorium, or beryllium in appreciable quantities have not been found associated with the important copper, lead, zinc, silver, chrome, manganese, and tungsten mines in the interior of the shield.

Prospecting the South African Shield is a different problem from prospecting in Canada. Access by automobile and aircraft is generally simpler, and the climate, although often uncomfortably hot, permits year-round prospecting. Climatic conditions vary from hot, arid desert in the southwest, through dry semi-arid regions, to subtropical and tropical savannah country, with dry and rainy seasons in the northeast. Prospecting is probably permissible in most of the area with certain restrictions and in accordance with mining laws that vary from country to country. In the Congo, however, exclusive concessions are held by major companies. Angola and Mozambique are Portuguese territory, the Rhodesias are British territory, and the rest of the shield area, comprising Southwest Africa and the Union of South Africa, is under the jurisdiction of the Union.

AUSTRALIAN SHIELD

The Australian, or Western Australian, Shield occupies most of the western two-thirds of the continent, including nearly all of the states of Western Australia and South Australia and the Northern Territory. It contains nearly all of the known Australian occurrences of uranium and beryllium. Thorium minerals are known in granite, pegmatites, and placers. Again, the known occurrences of uranium are along the edges of this shield.

The Katherine-Darwin area of the Northern Territory, about 150 miles square, in which the Rum Jungle deposits are located, is the most important potential uranium-producing area, and perhaps the best prospecting area in Australia. It is traversed from southeast to northwest by the Australian Defence Highway which terminates in Alice Springs and Darwin. Since the Rum Jungle discovery, uranium has been found in several new localities, among them the Katherine-Edith River area, the Brocks Creek district, and Coronation Hill. The geologic features of this area make it favorable for both the Rum Jungle type of deposit and the high-grade pitchblende vein deposits.

Another important prospecting area is along the extreme southeastern edge of the shield in southeastern South Australia. Here are located the Radium

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Hill davidite deposits and the oxidized deposits of Mt. Painter and East Painter in the Flinders Ranges about 150 miles northwest of Radium Hill. This area should provide additional deposits similar to Radium Hill or to the Crocker's Well deposit¹ which may become a producer, and the possibility of finding other types of deposits should not be overlooked. Numerous small occurrences of davidite, brannerite, and the secondary minerals are known at other localities in this area, and in 1953, rich pitchblende mineralization of unknown extent was discovered at Myponga, south of Adelaide.

Western Australia, comprising more than half of the Australian Shield, is a third important, but little explored, prospecting ground for uranium, thorium, and beryllium. All three are constituents of pegmatites at several localities. Significant uranium discoveries in 1954 made the Mt. Isa copper-lead-zinc district, northwestern Queensland, a fourth important uranium area.

The most important beryl-producing areas are Londonderry, in southwest Western Australia, and Wodgina, near Port Hedland, on the northwest coast of Western Australia. Pegmatites containing beryl also occur in the Harts Range, Northern Territory, and at Mica Creek, Queensland, and Broken Hill along the eastern edge of the shield, a region that may also represent a favorable area for beryl discoveries. Vein deposits of thorium are not unlikely in the Australian shield. Occurrences of undetermined importance have recently been reported in the Northern Territory.

A large part of the central area of the Australian Shield is very difficult to explore, and this may explain in part why known occurrences are along the shield edge. In addition, large areas are without rock outcrops, covered by sandy deserts and dry lake beds. Climatically, the Australian Shield is in many ways similar to the Rhodesian Shield, with arid conditions predominant except for a narrow coastal strip and the subtropical savannah country in the north. The border areas of the shield are accessible by jeep or truck, and, while prospecting is possible the year round, it becomes very hot in the south and wet in the north during the summer (November to April). Private prospecting is encouraged in Australia, and claims may be staked or leases obtained for uranium in most areas except in South Australia.² A reward of up to £A 25,000 is offered by the Australian Commonwealth government for a new discovery of uranium meeting certain requirements. The maximum reward was collected by the discoverer of the Rum Jungle deposits.

BRAZILIAN SHIELD

The Brazilian Shield comprises Uruguay and all of Brazil south of the Amazon River, except the northwestern state of Amazonas. The entire coast-

¹ See description of the mineral *brannerite* in Appendix I.

² Although private mining of uranium is not permitted in South Australia, the State government provides rewards for uranium discoveries.

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line of the shield and the diamond and gold placer deposits along the inland rivers are good prospecting grounds for monazite. However, the best area is along the coast between Rio de Janeiro and Natal. Uruguay, and the eastern border area of the shield inland from the coast for 300 to 400 miles, is generally favorable for beryl, but the best deposits have been found in the north and central parts of that zone. The relatively unexplored northern and western edges of the shield may also have beryl deposits.

The baddeleyite-zirkelite¹ deposits of the states of São Paulo and southern Minas Gerais in the southern part of the shield, particularly those at Poco de Caldas, are potential sources of both thorium and uranium. Other deposits of that type may exist in southern Mato Grosso. Although the Brazilian pegmatites are among the richest in uranium in the world, none of them has yet proved to be a source of more than a few tens of tons of primary uranium minerals. The areas of beryl-bearing pegmatites in the eastern border region are not considered particularly favorable for uranium other than in pegmatites.

If the relation of uranium provinces to shield borders holds, the entire western and northwestern border of the Brazilian Shield, including the Brazilian-Paraguayan and Brazilian-Bolivian boundary regions, may be a favorable prospecting area for uranium. Pegmatites containing both uranium and beryllium and placers with uranium and thorium minerals have been reported in eastern Bolivia. Much of this area, particularly along the northwestern edge of the shield, is some of the wildest and least-explored country in the world. Access to it has been attained only by major expeditions adequately equipped for complete self-maintenance and for protection from hostile Indians.

The entire Brazilian Shield, except for the most southern parts, is tropical with equatorial temperatures. A large part of the eastern border region is covered by jungle or semi-jungle tropical growth and, except in the most active mining areas, roads are few. Access to many of the coastal monazite areas, particularly to the more northerly ones, requires aircraft or boat to the nearest landing or docking facility and travel from there by foot or muleback. Mules are required in much of the inland area as well.

GUIANA SHIELD

The Guiana Shield is very similar to the northern part of the Brazilian Shield, of which it is really an extension. (They are separated only by the Amazon River valley.) It includes that part of Brazil north of the Amazon, the two southeast Venezuelan provinces of Amazonas and Bolivar, the easternmost corner of Colombia, and the Guianas. Most of the Guiana Shield is as little explored as the wildest part of the Brazilian Shield, and access is possible only by aircraft, boat, and muleback. Some gold and diamond placer mining

¹ See Appendix II—Other Thorium Minerals.

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is carried on in the Guianas and southern Venezuela, and both thorium and refractory uranium minerals have been found in some of the gold placers. Pegmatites containing beryl and uranium minerals have also been reported.

An extensive series of flat-lying sedimentary rocks, including thick sandstone formations, overlies the shield in the Gran Sabana of southern Venezuela and central British Guiana, giving the area characteristics very similar to parts of the Colorado Plateau. This area is potentially favorable for carnotite, copper-uranium and other deposits in sandstones. The northern edge of the shield, just south of the Orinoco River in Venezuela, has extensive iron, manganese, and aluminum deposits, as well as gold-quartz veins. The possibility of primary uranium or thorium mineralization in this area, as well as in the less-explored southern and western borders, cannot be excluded. The prospecting and mining regulations of six countries are involved for anyone attempting to prospect this area, but all of them have some provision for private prospecting.

INDIAN SHIELD

The important beryl and monazite deposits of India and Ceylon are situated around the edges of a shield-like area comprising all of the southern peninsula of India. The entire coastline of the peninsula and of Ceylon is potentially favorable for monazite. Most of the inland area of the shield, particularly the known pegmatite areas, is good prospecting ground for beryl and possibly thorium vein deposits. Specimens of uranium minerals have been found in some of the pegmatites and other occurrences have been reported, but the Indian Shield does not appear particularly favorable for important uranium deposits.

SCANDINAVIAN SHIELD

The Scandinavian Shield embraces Norway, Sweden, Finland, and the Karelia and Kola districts of the U.S.S.R. There are pegmatites in most of the border areas of this shield, those of Karelia being among the few from which some uranium has actually been produced. The pegmatites of Norway are noted for their production of rare pegmatite minerals. They have furnished the world's entire supply of gadolinite,¹ as well as minor amounts of beryl and phenacite. These pegmatites also contain some uranium minerals and a little monazite. There does not appear to be much chance in the Scandinavian Shield for other than pegmatite occurrences of uranium and perhaps minor beryl. Exceptions are the uranium-bearing alum (Kölm) shales of southern Sweden.

OTHER SHIELD OR SHIELD-LIKE AREAS

The southeast Asia area of Indo-China, Thailand (Siam), Malaya, and Borneo is composed of granitic and metamorphic rocks and has shield charac-

¹ See Appendix II—Other Thorium Minerals.

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teristics. Much of this region, particularly the western and southern parts, including Siam, Malaya, Borneo, and the small islands of Bangka, Billiton, and Singkep, is favorable for monazite and includes the world's major tin placers. Some uranium pegmatite minerals are found in the placers. Occurrences of autunite have been reported in northern Indo-China in Tonkin near the Chinese border. This northern edge of the shield-like area is a potentially favorable primary uranium province.

There are three shield areas of which little is known in the U.S.S.R. and China. The Tibetan Shield, a much younger and higher area than most shields, includes Tibet and western Sinkiang, and is adjacent on the southeast to the Turkistan deposits of secondary minerals at Kara Tau, Tyuya Muyun, and Ferghana. The Angara Shield is located between the Yenisei and Lena rivers in north-central Siberia and is reported to have abundant monazite.

XIII

MASSIFS

A second type of structure on the earth's surface that seems to have more than average favorability for primary uranium occurrences is the *massif*. This term is variously defined but is used here to describe areas or blocks of the earth's crust, composed mostly of granitic and metamorphic rocks and similar in many respects to shields, but smaller in area and often younger and more mountainous. The term "massif" is also applied to narrow mountain ranges, but these structures will be described separately. The massifs which appear to have the greatest favorability for large, high-grade primary uranium deposits are the roughly equa-dimensional mountainous areas. Massifs are less favorable for important thorium and beryllium deposits than they are for uranium deposits.

BOHEMIAN MASSIF

Two of the three richest primary vein deposits of uranium, at Shinkolobwe and Great Bear Lake, are associated with shield structures; the third, at Joachimsthal, is in the Bohemian Massif, which occupies the western half of Czechoslovakia and the adjacent areas of southern Saxony and eastern Bavaria. The Joachimsthal and other similar pitchblende deposits near the towns of Freiburg, Schneeberg, and Johanngeorgenstadt are located in a mountain range called the Erz Gebirge on the north edge of the massif along the border of western Czechoslovakia and Saxony. Other lesser deposits are known to the south of Joachimsthal as far as Marienbad. Minor occurrences, which have not yet produced ore, are found in the Bohemian Forest area of Bavaria west and south of Joachimsthal near Weissenstadt and Wolsendorf. At Wolsendorf uranium is associated with fluorite. The entire Erz Gebirge region has been actively prospected and worked by the Russians. The eastern Bavaria area of the American Zone of Germany, adjacent to the Bohemian Forest and extending through the Bavarian Forest and into Austria north of the Danube River, is a favorable area for uranium prospecting. The Bohemian Massif is not known to be particularly favorable for beryllium or thorium.

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SPANISH MESETA

The Portuguese deposits represent the fourth most productive group of the historic primary vein deposits and are situated in the west-central part of the Spanish Meseta, a mountainous area occupying the central and western parts of the Spanish peninsula south of the Pyrenees Mountains. Although the north-central part of Portugal is the most favored area, the entire Meseta represents potentially favorable ground for uranium. Occurrences have been reported in Spain in Leon in the north and Cordoba in the south. These have included uranium minerals associated with copper, lead, silver, and cobalt in veins and replacement deposits and pegmatite occurrences. Although the presence of pegmatites in many parts of the Meseta might be taken as an unfavorable sign, the area may be favorable to both vein and pegmatite deposits.

Beryl is found in many of the Portuguese pegmatites and to a lesser extent in the pegmatites of Spain. Very small beach placers containing ilmenite and monazite at Balares, at the northwest corner of Spain, represent the only known occurrences of thorium in the Meseta other than in pegmatites.

MASSIF CENTRAL AND ADJACENT AREAS

The area of south-central France lying between, and to the south of, Limoges and Lyon is known as the Massif Central. The northern edge of this area has most of the known primary uranium veins (with surface oxidized zones similar to the Portuguese deposits) that have provided all of the production from metropolitan France. The entire massif, particularly around the borders, is favorable prospecting ground.

The Massif Central and the Bohemian Massif are parts of the larger mountainous complex of western Europe sometimes considered as one structural unit. This belt or complex includes also the Vosges Mountains of France and the Black Forest area of Germany, divided north and south by the Rhine River between Strasbourg and Basel. Both primary and secondary uranium minerals have been identified in the lead-silver-cobalt mining district northeast of Freiburg. The western border of the Italian Maritime Alps represents another favorable hunting ground for uranium. The Cuneo-Liguria deposits which are somewhat similar, at least at the surface, to the French deposits, are located here, and additional occurrences of uranium have recently been reported. None of the western European mountain areas appear to have particular favorability for beryllium or thorium.

Regulations concerning prospecting for and mining of uranium, thorium, and beryllium vary widely throughout Europe. With the exception of Spain, private activity is permitted to some degree in most areas.

MASSIFS

BRITISH UPLANDS

A physiographic unit with massif characteristics comprises Brittany and Normandy in France and Cornwall, Wales, Scotland, and Ireland. The uranium deposits of Cornwall and Wales and recently found occurrences in Vendée near Les Herbiers, southeast of Nantes, represent the extent of known uranium mineralization. As a result of the recent discovery, the southeastern edge of the French sector may be good prospecting ground for the type of occurrence found in the Massif Central. The United Kingdom is less favorable for new discoveries in view of the active prospecting there for hundreds of years and the intensive examination of favorable areas for uranium by British geologists during the past decade. There have been no occurrences reported from Ireland.

None of this area is favorable for beryllium or thorium.

RHODOPE MASSIF

The Rhodope Massif lies in western Bulgaria, eastern Yugoslavia, northern Greece, and European Turkey. Deposits of secondary minerals in fracture zones which may have primary minerals at depth are known at Bukhovo and Strelchna, Bulgaria. The extensions of the massif into Macedonia, Yugoslavia, and Turkey are potentially favorable prospecting grounds. Beryllium and thorium are not known in the region, although beryl pegmatites and monazite placers may possibly be found in the granite areas.

XIII

OTHER AREAS OF GRANITIC AND METAMORPHIC ROCKS

There are three other areas of crystalline rocks which should be mentioned. They are not shields or massifs, but they do have the type of general geologic environment favorable principally for primary mineralization.

EAST AFRICAN HIGHLANDS

A nearly continuous, wedge-shaped area of granitic and metamorphic rocks extends northward along the east coast of Africa from the northeast border of the South African Shield to the Nile delta. The area is rich in pegmatites and has some granite bodies of unusually high uranium and thorium content, particularly in Uganda. Thin uranium-bearing slate formations have also been reported. The Mozambique pegmatites are unusually rich in the uranium-bearing columbium minerals, and the pegmatites of the Uluguru Mountains of eastern Tanganyika are reported to have unusual amounts of uraninite. The pegmatites of Madagascar are also unusually rich in uranium and have provided a small production. A somewhat larger uranium production has come from the davidite deposits of Mozambique. Apart from these deposits, the region shows little promise of uranium.

The granite-pegmatite environment, however, is favorable for thorium-bearing river and beach placers and for beryllium deposits. Madagascar is an important producer of beryl, and some production has come from Mozambique, Uganda, Kenya, and Tanganyika. Monazite is widespread in the sands of the area. There are extensive areas of monazite-bearing sands along the east coast of Madagascar, and some thorianite has also been reported. Small amounts of monazite have been recovered with ilmenite at Damietta and Rosetta on the Nile River delta, and it has been reported from river or beach sands of Mozambique, Uganda, Kenya, Tanganyika, Nyassaland, and Somaliland. Some refractory uranium minerals have also been found in several of these deposits.

No important occurrences of atomic energy minerals have been established in Ethiopia, Eritrea, or eastern Sudan.

OTHER AREAS OF GRANITIC AND METAMORPHIC ROCKS

MID-AFRICAN HIGHLANDS

The Mid-African Highlands extend northwest from the South African Shield toward the hump of Africa. They include northern Angola, the western Congo, Nigeria, the Gold Coast, Liberia, Sierra Leone, Senegal, and the southern parts of French West Africa and French Equatorial Africa. This region is probably more favorable for uranium than the East African Highlands. The most favorable area is in the Moyen Congo in the southern part of French Equatorial Africa adjacent to western Belgian Congo, where there are copper deposits similar to those of Northern Rhodesia. Uranium has been found in at least one of these deposits in the Niari basin. A similarly favorable area for primary uranium may exist in northern Angola where uranium has also been reported. Uranium deposits in sandstone may occur in western Angola. Elsewhere in this region uranium possibilities appear to be limited to the unusually radioactive columbium-bearing granites of Nigeria and French West Africa and to the phosphates of Nigeria and Senegal. Monazite occurs in the beach sands of Sierra Leone and in the river gravels of southern Gold Coast and may be present elsewhere along the West African coast. High-thorium granites are reported in the western Congo. The columbite-bearing tin placers in central and southern Nigeria contain monazite and thorite and may contain the refractory uranium minerals as well. Beryl occurs in pegmatites of the Kabba district, Nigeria, and probably in many other areas of granitic rocks.

JAPANESE AND KOREAN HIGHLANDS

That part of Honshu Island, south of Tokyo, together with northern Kyushu, Korea, and southern Manchuria, forms a mountainous area of crystalline rocks that might be favorable for primary uranium deposits. However, as in many such areas, the known uranium is restricted to the numerous pegmatites. Production of uranium minerals in quantities of a few hundred tons during World War II from some of the Manchurian pegmatites has been reported, but those of Korea and Japan have yielded only specimens. Many of the Korean pegmatites are rich in beryl, which has been mined in both North and South Korea, and massive monazite. The gold placers along the rivers of central Korea contain monazite in commercial quantities, and some of the placers contain refractory uranium minerals. Some of the Korean beaches, especially along the east coast, are reported to contain monazite.

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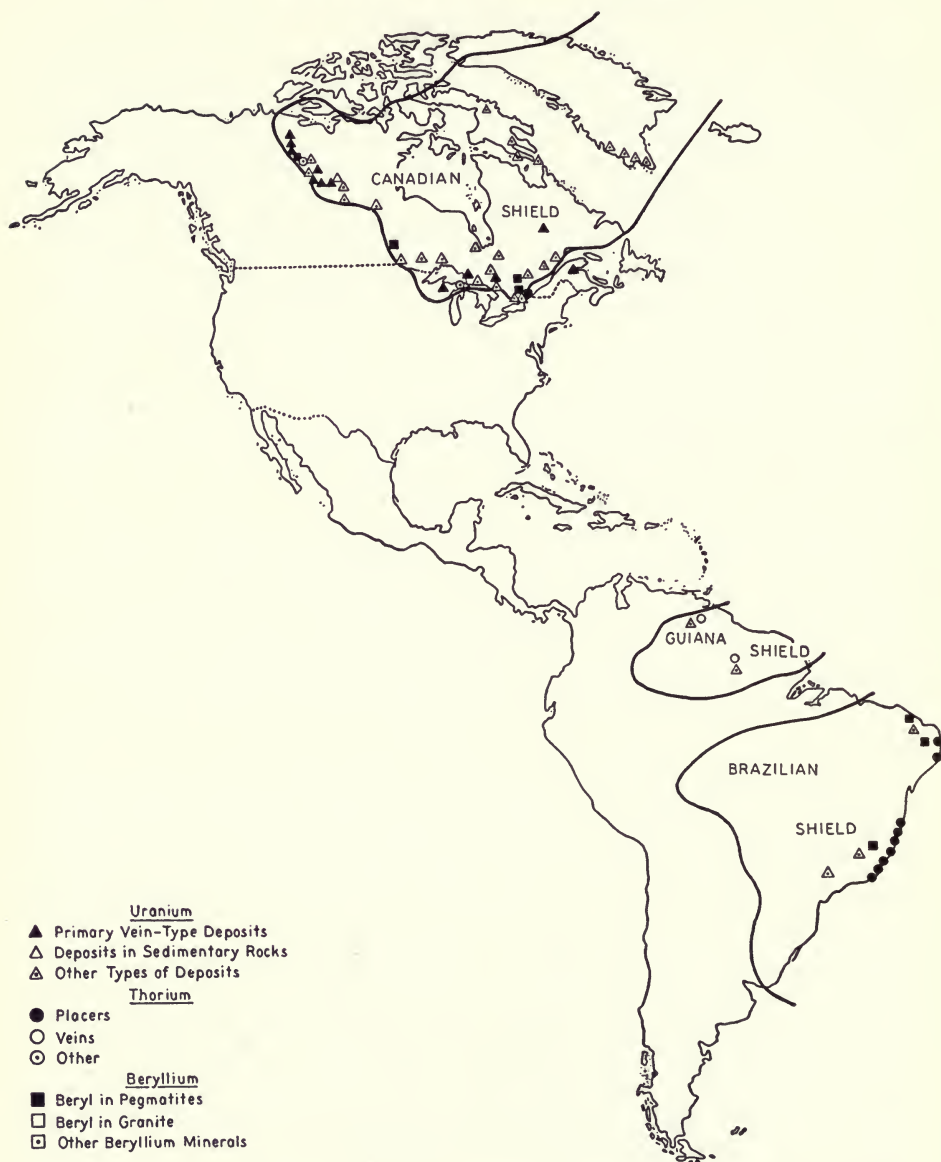


PLATE XVA. Relation of Occurrences of Uranium, Thorium and Beryllium to Shields, Massifs and Similar Areas of the World.

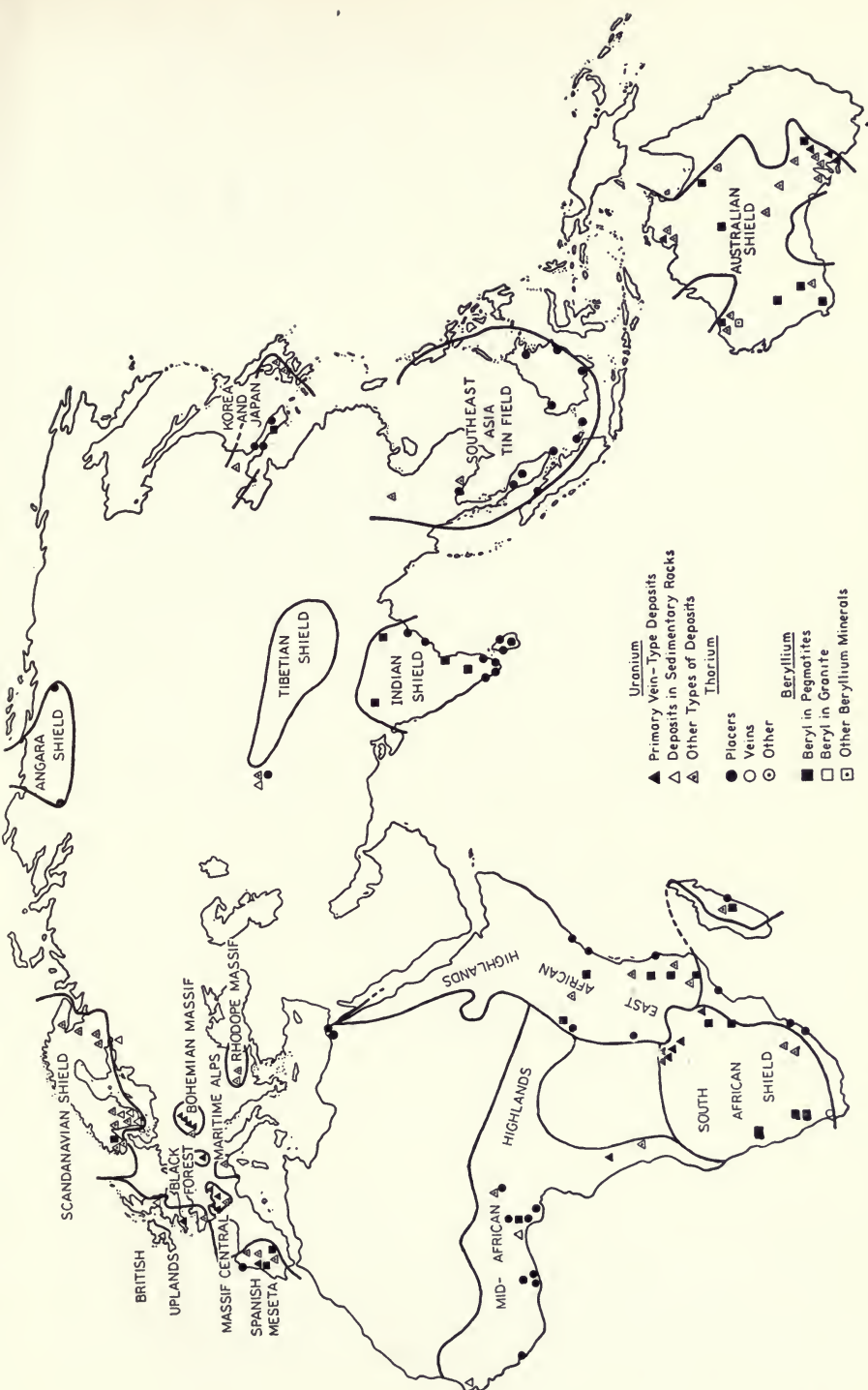


PLATE XVB. Relation of Occurrences of Uranium, Thorium and Beryllium to Shields, Massifs and Similar Areas of the World.

XIV

PRINCIPAL MOUNTAIN SYSTEMS OF THE WORLD

The distribution of the largest and richest primary vein-type deposits of uranium has indicated that certain major shields and massifs offer the best possibilities for additional deposits of major importance. Most of such areas are also favorable prospecting grounds for thorium and beryllium.

The principal mountain systems of the world are another group of major structural features of the earth providing favorable prospecting ground for deposits of atomic energy minerals. In addition to large areas of granitic and metamorphic rocks favorable for uranium vein deposits, they have associated intermontane basins and plateaus with extensive sedimentary formations of the types most favorable for the flat-lying uranium deposits. They also offer possibilities for all other types of uranium deposits. These structures have been prodigious producers of other metals throughout the world, and in the United States they have provided the principal production of uranium, thorium, and beryllium.

NORTH AMERICAN CORDILLERA¹

The North American Cordillera is one of the largest and most richly mineralized areas in the world. This fact alone recommends it as a prospecting ground for minerals for atomic energy. Although it is possible that this area will never be found to contain another Shinkolobwe or Great Bear Lake deposit, or comparable deposits of thorium or beryllium, it undoubtedly will continue to develop as it has in the last few years as an increasingly important region of numerous smaller or less rich deposits which, together, may eventually surpass in productivity any other region. Thus, it is one of the most attractive regions for the prospector.

This huge mountain system occupies the western third of the United States, nearly all of Alaska and Mexico, and most of British Columbia and the Yukon. It is divided lengthwise into three major units: the Rocky Mountain System, the Inter-mountain Plateau System, and the Pacific Mountain System. Occurrences of atomic energy minerals are known in all three divisions from Alaska to Mexico, but all production to date has come from the Rocky Moun-

¹ In this use, a general term for an entire physiographic province.

PRINCIPAL MOUNTAIN SYSTEMS OF THE WORLD

tains and the inter-mountain plateaus, basins and ranges to the west within the United States. These two areas, comprising all or part of each of the nine western states, Montana, Wyoming, Colorado, New Mexico, Arizona, Utah, Idaho, Nevada, and California, have examples of nearly every type of uranium deposit as well as substantial beryl deposits, and both vein and placer thorium. They include the best prospecting ground in the United States.

Rocky Mountain System. The Rocky Mountain System is made up of the Arctic Rockies and the Northern, Middle, and Southern Rocky Mountains.

The *Arctic Rockies* extend from Northern Alaska through the Yukon Territory to British Columbia. They include the Brooks Range of Alaska and the Mackenzie, Franklin, and Richardson mountains. These ranges comprise one of the least explored areas of the world because of their remoteness and their extremely cold climate for eight months out of the year. They have attracted only the most rugged prospectors, primarily in search of gold. In spite of the legendary reputation of Alaska and the Yukon since the gold rush days, the Arctic Rockies have not proved particularly well mineralized and, in general, they do not appear to be a favorable prospecting ground for atomic energy minerals. The only reported occurrences of these minerals are uranium-bearing phosphate and shales in the Brooks Range. However, as access to the area is improved and exploration increases, this outlook may change.

The *Northern Rockies* comprise the main Canadian Rockies of eastern British Columbia, the Purcell and Selkirk Mountains in central British Columbia, and the less imposing ranges which extend southward through the Idaho batholith of central Idaho. The Canadian Rockies are not well mineralized, but uranium in low-grade vein-type deposits occurs about 70 miles north of Kamloops, British Columbia, and there are pegmatites with radioactive minerals southeast of Prince George, B.C. The Montana-Idaho section of the Northern Rockies is much better mineralized. It includes the famous Coeur d'Alene, Idaho, lead-silver district and the Butte, Montana, copper district, as well as the monazite deposits of central Idaho and the small uranium vein deposits of the Boulder, Montana, area.

Pitchblende has been found in five different mines in the Coeur d'Alene district since it was first discovered in the lower levels of the Sunshine Mine in 1948. The possibility of discovering commercial primary uranium ore in moderate amounts in the mines of the Coeur d'Alene, Butte, and Boulder districts, or in other less known districts, is considered good. The surface expression of deposits in this area is most likely to be fracture coatings of yellow secondary minerals. In the deeper mine workings, however, fine-grained pitchblende or uraninite, accompanied by typical red staining, is to be expected.

New placer deposits of monazite are continually being discovered in the central Idaho and southwest Montana areas, and some of these contain the

MINERALS FOR ATOMIC ENERGY

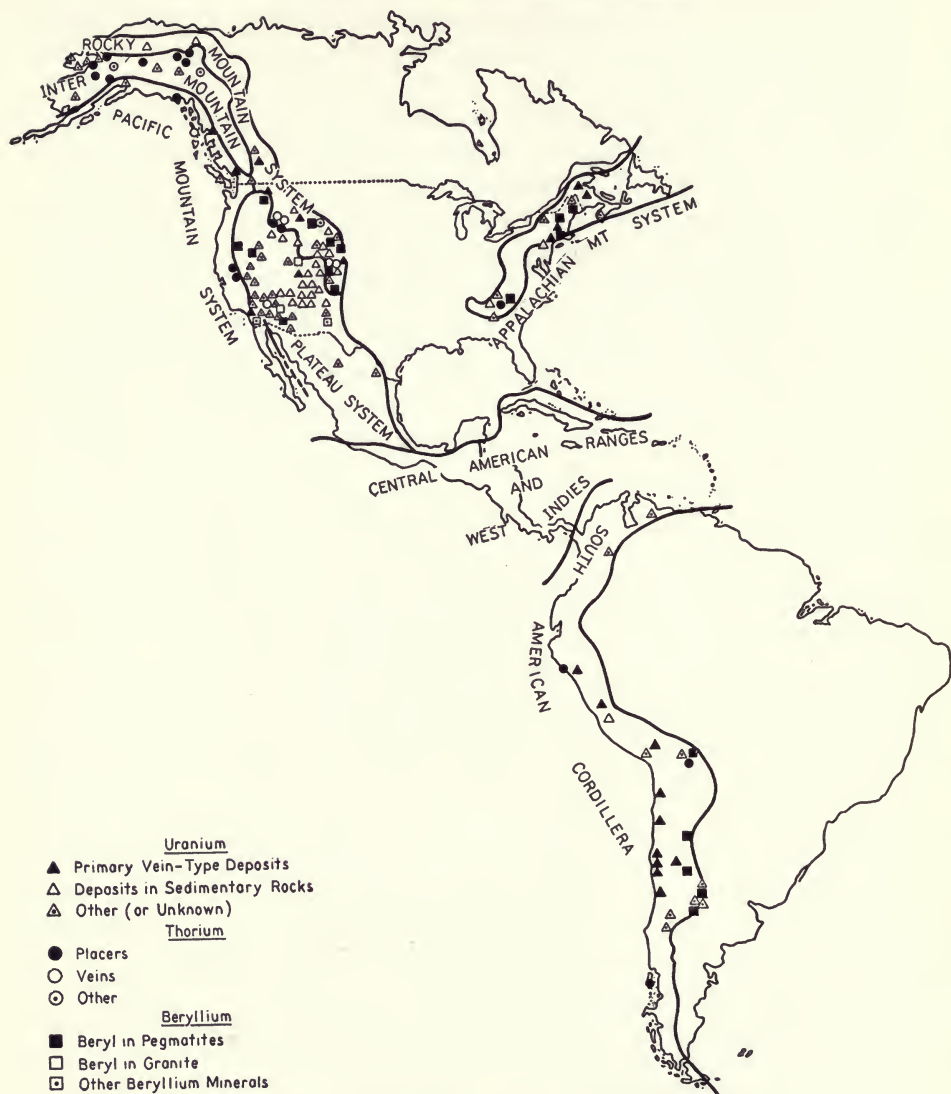


PLATE XVIA. Relation of Occurrences of Uranium, Thorium and Beryllium to Principal Mountain Systems of the World.

refractory uranium minerals and may soon provide uranium as a by-product of the columbium and tantalum which these minerals also contain. Lemhi County, Idaho, offers one of the best prospecting localities for primary vein deposits of thorium. Several monazite veins in metamorphic rocks, some up to

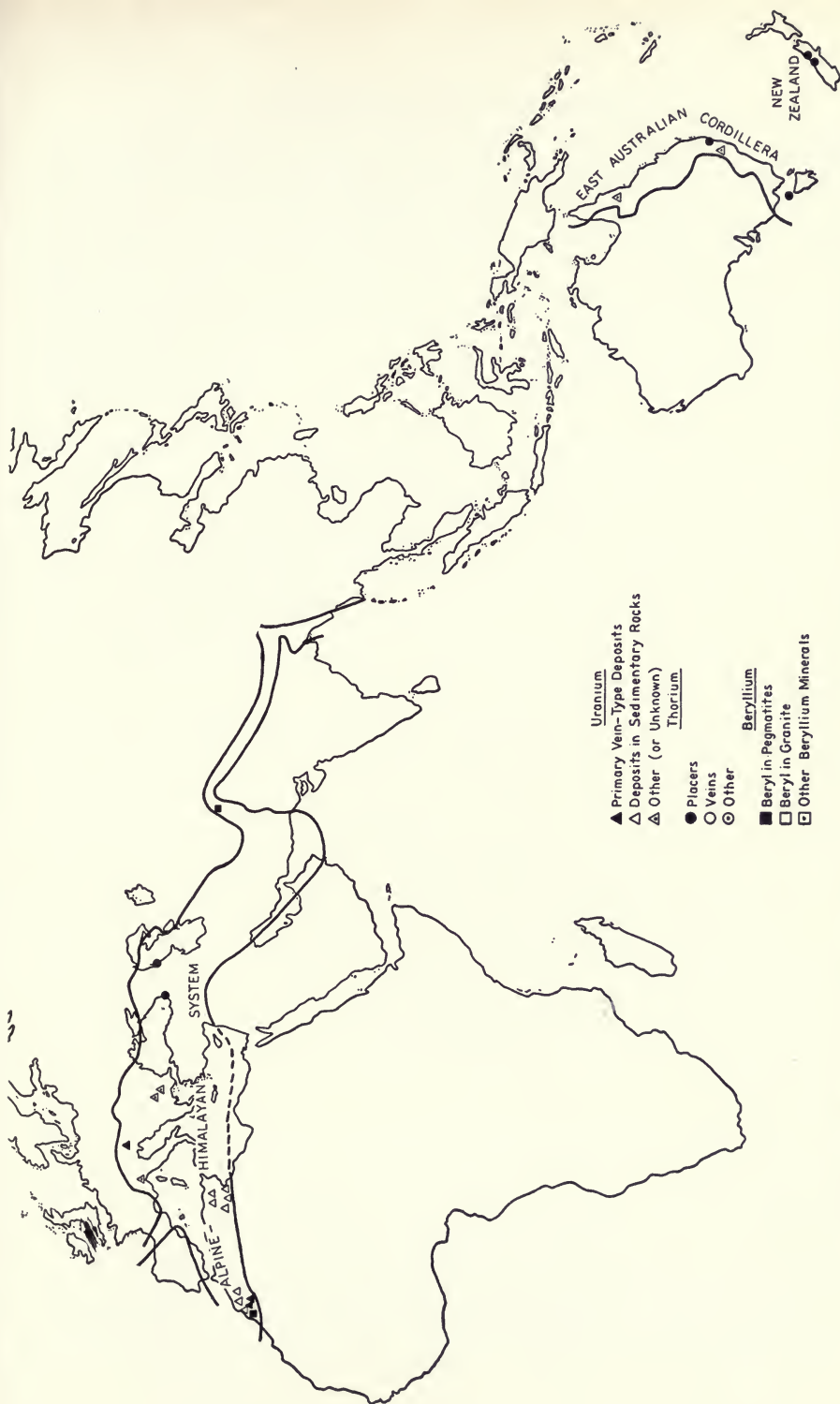


PLATE XVIIIB. Relation of Occurrences of Uranium, Thorium and Beryllium to Principal Mountain Systems of the World.

10 feet in width, were found at Mineral Hill, near Shoup in 1952, and vein deposits of thorite have been known since 1950 near Lemhi Pass. Pegmatites containing some beryl also occur in the Idaho-Montana section of the Northern Rockies; the best known deposit is the Muscovite mine, Latah County, north-west Idaho. Lastly, the uranium-bearing Phosphoria formation of phosphate rock occurs in areas around Helena and Dillon, Montana; and, although the formation has been studied for several years by the U. S. Geological Survey, there is always the possibility that areas or beds of unusually high uranium content have yet to be discovered. These rocks also occur in southern British Columbia.

The *Middle Rocky Mountains* are a group of several short mountain ranges and intervening basins covering the western two-thirds of Wyoming, the extreme southern part of Montana, the northeast corner of Utah, and southeast corner of Idaho. They include the Big Horn Mountains and Big Horn Basin in northwestern Wyoming, in the north, and the Wasatch Range and Uinta Mountains east of Salt Lake City, Utah, in the south. The fossil monazite placers in the Deadwood formation are located at the northern end of the Big Horn Mountains, and the Wamsutter schroeckerite deposit is in the Wyoming Basin to the south.

The sedimentary rocks in the basins of this region are excellent prospecting areas for plateau-type deposits; similar formations in the Powder River Basin and western Black Hills area to the east and northeast have carnotite deposits. Secondary uranium minerals have been found recently in limestones, limey sediments, and sandstones as young as Miocene in age in the Miller Hill area and in other parts of southern Carbon County, Wyoming, and at several points in the Big Horn Basin. The most significant discovery, however, occurred in 1953 in the Wind River (Shoshone) Basin about 70 miles west of Casper, Wyoming, where secondary uranium minerals and probably some primary minerals occur in apparently flat-lying beds in coarse sandstones of Eocene age and older. The Big Horn, Green River, and Wyoming (Washakie) basins and the smaller basins northeast of Laramie are favorable locations for additional, similar deposits.

Uraninite and gummite were identified in a quartz-carbonate vein in pre-Cambrian schist in the Owl Creek Mountains at the northeast edge of the Wind River Basin in 1954, but other than this, only a few pegmatites containing small amounts of beryl and minor uranium and thorium occurrences are so far known in the mountainous ranges between the basins.

The lignites of the Red Desert area, Wyoming, in the south offer possibilities for large low-grade deposits. The Deadwood formation should also be thoroughly prospected for additional monazite deposits. Although no occurrences

PRINCIPAL MOUNTAIN SYSTEMS OF THE WORLD

are known, the possibility of finding vein deposits in the Park City mining district in the Wasatch Range should not be overlooked. Plateau type deposits of importance may occur on the flanks of the Uinta Mountains. The uranium-bearing Phosphoria formation is present in the vicinity of Bear Lake on the Idaho-Utah border.

The *Southern Rocky Mountains* are the highest and most formidable mountains of the North American Cordillera. The Front Range, running across the center of Colorado from north to south, is the most spectacular, rising from the Great Plains on the east to an elevation of 14,000 feet within a distance of about 30 miles. The Southern Rockies are also among the most intensely mineralized and extensively prospected areas in the United States and have been a major producer of gold, silver, molybdenum, lead, and zinc. The area includes such well-known mining districts as Central City, Climax, Leadville, Cripple Creek, Telluride, Durango, and Silverton. In addition to the Front Range, the Southern Rockies include the Sawatch, San Juan, and Sangre de Cristo mountains, the latter forming the southern extension into New Mexico as far south as Santa Fe.

The Southern Rockies comprise largely granite and metamorphic rocks and are favorable prospecting ground for primary deposits of uranium, thorium, and beryllium. In addition to the numerous pitchblende occurrences in Clear Creek, Gilpin, Boulder, and Larimer counties in the Colorado Front Range, uranium has been found with tungsten and fluorite in the Jamestown, Colorado, district, and in lead, silver, and copper deposits in the San Juan Mountains. Plateau type occurrences have also been found in sandstones in sedimentary areas in Grand and Huerfano counties, Colorado, and uranium occurs associated with coal at La Ventana, New Mexico. Thorite-bearing veins are known in the Powderhorn district southwest of Gunnison, and in the Wet Mountains west of Pueblo, Colorado. Beryl deposits occur in the Crystal Mountain district, Larimer County; the Quartz Creek district, Gunnison County; and in Clear Creek County, Colorado. The Petaca district northwest of Santa Fe, New Mexico, also has numerous pegmatites containing beryl and minor amounts of uranium.

The Southern Rocky Mountains, particularly the Front Range, may rightfully be called a uranium and beryllium province and may prove to be a thorium province as well. Although no large deposits have yet been found, there are so many small occurrences of uranium, thorium, and beryllium, that this area must be considered a good prospecting ground.

Inter-mountain Plateau System. A series of intermittent plains, plateaus, short mountain ranges, and basins separate the Rocky Mountain System from the Pacific Mountain System from Alaska to Mexico. Of these, the three south-

ernmost, the Colorado Plateau, the Basin and Range Province, and the Mexican Highlands, offer the best hunting ground for uranium, and the last two offer good prospects for thorium and beryllium as well.

The *central Alaskan uplands and plains* have supplied numerous samples of uranium and thorium minerals, but the discovery of commercial deposits does not appear likely. Minor occurrences of secondary uranium minerals have been found associated with copper and tin ores northwest of Nome on the Seward Peninsula. Uranothorianite occurs in placers on the Seward Peninsula and Kuskokwim Upland, western Alaska, and throughout an area in eastern Alaska bounded roughly by Chandalar and the Porcupine River at the Yukon boundary on the north and Beaver and Eagle on the Yukon River on the south. Ellsworthite in placers and uranothorite in granite have been found in the Ruby-Hot Springs area of central Alaska. Monazite probably also occurs in small amounts in many Alaskan gold placers. The interior plateaus of the Yukon and British Columbia do not appear to contain significant occurrences of atomic energy minerals, although allanite and monazite have been found in granite in the Mayo district, Yukon.

The northernmost of the three major units separating the Rocky Mountain and Pacific Mountain systems in the United States is the *Columbia Plateau* occupying the eastern half of Oregon, the southeastern quarter of Washington, and the Snake River plain in southern Idaho. Much of the Columbia Plateau is covered with young (Tertiary) lava flows and no significant occurrences of atomic minerals are known in the lavas. Uranium-bearing lignites and coals are found in Payette, Twin Falls, and Cassia counties, southeastern and southern Idaho.

The Columbia Plateau is bounded on the south by the *Basin and Range Province* which occupies all of Nevada, southeastern California, and western Utah, as well as the portions of Arizona and New Mexico south of the Colorado Plateau, and northern Mexico. It is largely a barren or grass-covered desert and semi-desert area with an endless succession of short, rugged mountain ranges separated by flat, shallow basins. The province is sprinkled with major deposits of gold, silver, lead, zinc, and copper, including those at Tonopah, Carson City, and Eureka, Nevada; Darwin, California; Bisbie, Jerome, Prescott, Globe, Superior, and Morenci, Arizona; Silver City, New Mexico; Bingham Canyon, Utah; and numerous less important deposits. Only a few of the major deposits have even a trace of uranium, but many of the minor deposits have small amounts of secondary uranium minerals in the oxidized zone, and some primary minerals have also been found. Uranium has been found at fifteen or more localities in Nevada, particularly near Orovado (Humboldt County), Imlay (Pershing County), Austin (Lander County), in southern Lyon County, and in the Goodsprings—Las Vegas district (Clark County). It also occurs near

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Bakersfield, Mojave, Randsburg, Darwin, Baker, and Twenty-Nine Palms, southern California; in the Kingman and Hillside districts, Arizona; north and south of the Grand Canyon; in the Phoenix-Globe-Bisbie-Ajo area, Arizona;¹ and in the White Signal district near Silver City, New Mexico.

Most of these deposits show the bright yellow and green colors of the secondary uranium minerals in veins and rock fractures. Some of them also have primary minerals in complex ores of other metals, but none has yet proved good primary ore in depth with the important exception of the Marysvale, Utah, deposits on the western boundary of the Colorado Plateau. Other such deposits may be found, however. The uranium-bearing fluorite deposits of the Thomas Range, Juab County, Utah, and other similar deposits in New Mexico and Arizona are possible sources of by-product uranium.

Small quantities of beryl occur in pegmatites throughout the province, although very little has been mined. This province, however, has the three most important known nonpegmatite occurrences of beryl: the low-grade deposits in granite at Tungstona, near Hillside, Arizona; the deposits in the Sheep Rock Mountains, Utah; and the helvite deposits at Iron Mountain, New Mexico. Other deposits of these types are likely to be found as prospecting continues.

Important monazite or thorite vein deposits may be found in the vicinity of the Mountain Pass, California, and Gallinas Mountains, New Mexico, bastnäsite deposits and in other areas of similar geology. Minor occurrences of monazite exist in dry placers and pegmatites, particularly in Nevada and California.

The Basin and Range Province is unusually attractive from the standpoint of the prospector. Most of it is accessible the year round; it is crisscrossed by miles of highways and mining roads, and it contains many small mines and prospects waiting to be examined. The occurrences of uranium so far known are sufficient to encourage further prospecting in the area.

The *Colorado Plateau Province* is the most important single prospecting area in the United States and the second greatest uranium-producing area in the world. This entire area of more than 100,000 square miles covering eastern Utah, western Colorado, the northern half of Arizona, and the northwestern quarter of New Mexico is almost exclusively a prospecting ground for the medium-grade deposits in sedimentary rocks—carnotite deposits, roscoelite deposits, copper-uranium deposits, deposits in limestone, asphaltic deposits, or the newly discovered flat-lying pitchblende deposits. A few unusual deposits of vein characteristics, such as those near Placerville, have been found.²

¹In addition to the Red Bluff property (Chapter V) and several less productive occurrences in this area, the White Oak Mine, 15 miles northwest of Nogales, Arizona, produced a small tonnage of uranium ore containing the secondary minerals, kasolite, dumontite, uranophane, and autunite, from an oxidized lead vein in 1953.

²See description of thucholite, Appendix I.

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Only the Morrison formation of the small central area bounded by Thompsons and Blanding, Utah, and Durango and Grand Junction, Colorado, has been extensively prospected. The other formations in the central area, many of which are now proving to be very favorable, particularly for the pitchblende deposits like those in Big Indian Wash, and the northern, southern, and western parts of the Plateau, representing several times the area of the central part, have only begun to be prospected. Of these, the southern and southwestern areas (northern Arizona and southern Utah) are the most favorable for both carnotite

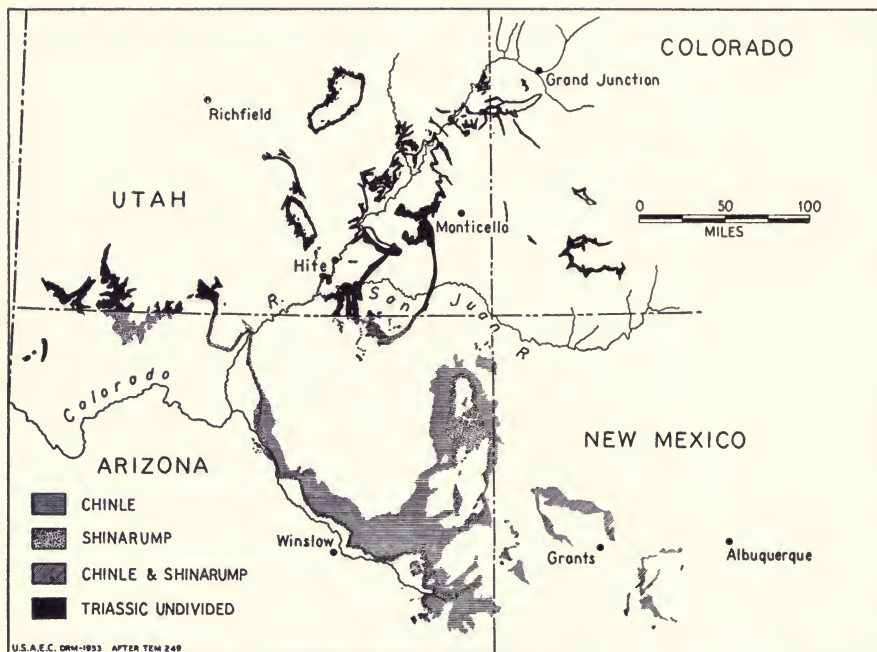


PLATE XVII. Triassic Outcrops, Colorado Plateau.

and copper-uranium deposits. Copper-uranium and asphaltic deposits, are found along the western fringe. Northwestern New Mexico, containing the Grants limestone deposits, has also become a very important area for carnotite deposits in sandstones, and one mineral deposit in shale has been found. The northeastern fringe of the Plateau has the high vanadium-low uranium roscoelite deposits. The Uinta Basin in northeastern Utah and the San Juan Basin in northwestern New Mexico are two specific areas that have been given little attention but which have sedimentary rocks similar to those found to be favorable both on the Plateau and in the Wyoming basins.

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Many of the more favorable areas of the Colorado Plateau are very difficult to reach, but new roads are continually being built, and with jeeps, trucks, airplanes, and even boats, the prospector is slowly reducing the area of the unexplored portions.

The *Mexican Highlands* comprise the Big Bend country of west Texas and all of Mexico, except narrow, eastern and western coastal strips, the Yucatan

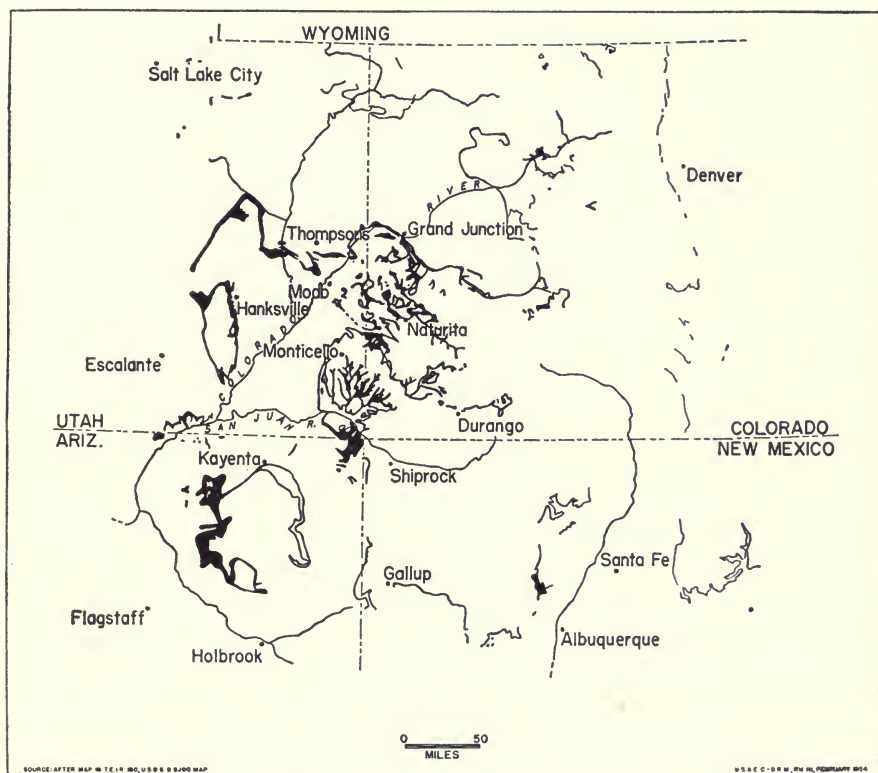


PLATE XVIII. Morrison Formation, Colorado Plateau.

Peninsula, and Baja California. The Highlands are really a combination of the southern extensions of the Basin and Range Province and the Rocky Mountains, having features similar to each of those areas. North of Mexico City the western Sierra Madre is separated from the eastern Sierra Madre by a high, semi-arid plateau, varying in elevation from 3,000 to 8,000 feet. South of Mexico City the entire country is mountainous with large areas of volcanic rocks which are part of the Pacific coast volcanic belt.

Mexico is noted for its silver, lead, zinc, and copper deposits, including those

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at Pachuca, Guanajuato, Zacatecas, Durango, Santa Barbara, and Cananea. Although only a few minor occurrences of uranium are known, and these are in northern Mexico, the entire Mexican Plateau is believed to be a favorable prospecting ground for primary or oxidized uranium deposits because of its intensive mineralization and its similarity to the favorable areas of Arizona and New Mexico. Mexico is not believed to be particularly favorable for thorium and beryllium, although minor occurrences no doubt exist. Much of Mexico is becoming accessible through the ever-expanding road network under construction by the Mexican government, and prospecting in most areas is possible the year round. Prospectors, however, should inquire in advance about regulations of the Mexican government applicable to uranium and thorium prospecting and mining.

Pacific Mountain System. The Pacific Mountain System comprises a coastal mountain chain extending from the Aleutian Islands to the tip of Baja California, Mexico, and parallel ranges a hundred miles or so inland including the Cascades and Sierra Nevada of Washington, Oregon, and California. Although some important mineral deposits occur in this province, particularly in Alaska and California, it is neither a heavily mineralized area nor a favorable area for the atomic energy minerals, in spite of the fact that some minor occurrences of uranium, thorium, and beryllium are known.

Carbonate-hematite veins containing thorite and monazite are known on Prince of Wales Island, and uraninite in pegmatites has been reported from the Willow Creek mining district north of Anchorage, Alaska. Small uraninite-bearing veins, similar in some respects to pegmatites but containing cobalt, nickel, and molybdenum, have been found in the Bridge River and Hazelton districts of British Columbia, and pegmatites occur in southern British Columbia. Specimens of secondary uranium minerals have been reported from Vancouver Island. The volcanic belts of the Aleutians and the Cascade Range from Mt. Lassen in Northern California to the British Columbia border appear to be barren of possibilities. The Washington, Oregon, and California coast ranges and Lower (Baja) California, although of different geology, have been equally unproductive of reports of atomic energy minerals. Exceptions are the minor thorite- and monazite-bearing beach sands south from San Francisco to Monterey which are similar to the South Island, New Zealand, beach sands.

The gold veins of the Sierra Nevada are also apparently barren, but the rich gold placers of the Great Valley of California between the Sierra Nevada and the Coast Ranges have minor monazite and thorite. Unfortunately, the amounts are too small to permit by-product recovery from gold dredging. Uraninite occurs as a minor constituent of a small metallic vein deposit near the north shore of Big Bear Lake, north of San Bernardino, and beryllium, uranium, and thorium minerals are minor constituents of pegmatites in the San Bernardino

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Mountains and in Riverside and San Diego counties, California. By and large, however, the Pacific Mountain System must be considered a poor prospecting area.

CENTRAL AMERICAN RANGES AND WEST INDIES

The mountain ranges and volcanoes of Central America form the connecting link between the North American and South American Cordillera. The same mountainous topography is also found in much of Cuba, Haiti, Santo Domingo, Puerto Rico, and Jamaica in the West Indies. Gold-silver veins and residual manganese deposits occur in Central America; iron, chrome, manganese, and nickel are mined in Cuba; and some copper and gold have been found in other parts of the West Indies. None of this region is believed to be particularly favorable for atomic energy minerals, although known metal deposits should be examined for uranium. A large part of Central America is made up of young volcanic rocks in which the gold-silver veins occur, but this geological environment has not proved favorable to uranium and thorium.

Prospecting and mining regulations vary from country to country, but some private activity is generally permitted. Land travel in much of Central America is difficult, and the climate in many parts is unattractive, although at higher elevations, which are the better prospecting grounds, this is less true.

SOUTH AMERICAN CORDILLERA

The South American Cordillera or Andean Mountain System is the southern equivalent of the North American Cordillera. These two great cordillera are very similar in physical characteristics, mineralization, and favorability for atomic energy minerals. The Andean System forms a much narrower belt than the North American Cordillera, but has the highest mountains in the Western Hemisphere. It extends from northern Colombia and Venezuela to the southern tip of Chile.

In Venezuela and Colombia and in northern Peru, the Cordillera is made up of three parallel mountain ranges, but in southern Peru and Bolivia there are only two major parallel ranges separated by a very high plateau called the Altiplano. In Ecuador and along the border of Chile and Argentina there is one main range with subsidiary parallel ranges at various points.

The northern end of the Cordillera (Venezuela, Colombia, and Ecuador) and the southern end (southern half of the Chilean-Argentine Andes) are less well mineralized and probably less favorable for uranium than the central part. However, the Andes in Peru, Bolivia, northern Chile, and northwestern Argentina have some of the most spectacular mineral deposits in the world, and numerous occurrences of uranium have been reported there. The sections of the Cordillera least favorable for uranium appear to be most favorable for thorium and beryl-

lium, with the exception of beryl from deposits in the subsidiary flanking ranges of the Argentine Andes. There has been no other significant production of these metals.

The *Venezuelan and Colombian Andes* have numerous pegmatites and granite areas, in some of which uranium and thorium minerals have been found. There is a possibility that commercial beryl deposits may also be found. The vein deposits comprise primarily gold and quicksilver which are not usually favorable associations for atomic energy minerals, but all vein deposits should be examined for uranium. The gold and platinum placers of the coastal Andes of Colombia offer poor possibilities for commercial quantities of monazite. *Ecuador* is not well mineralized, and its predominantly volcanic rocks are not favorable for atomic energy minerals.

Near Ricran, *Peru*, is the famous Mina Ragra mine, the largest vanadium deposit in the world. But Mina Ragra has no uranium. Peru is noted for its rich copper deposits at Cerro de Pasco, Morococha, San Cristobal, Casapalca, Youricocha, and Julcani. Peru also produces gold, silver, lead, zinc, bismuth, and antimony. These deposits do not appear to contain uranium, but it has been reported in vein deposits in southern Cajamarca in the north, near Cerro de Pasco in central Peru, and in Puno in the south. Peru is such a richly mineralized country, with large areas of favorable rocks, that the possibilities for additional uranium discoveries are good. The areas of the copper vein deposits and adjacent lead-zinc veins should be more thoroughly prospected.

Southern Peru is at the north edge of the region including northern Chile and Argentina and southwestern Bolivia which has numerous cobalt occurrences and which should be particularly favorable for pitchblende-cobalt mineralization. The areas of sedimentary rocks in the central Andes, particularly in Peru, Chile and Argentina, should also be prospected for deposits of the Colorado Plateau type. Traces of uranium are reported from the vanadium-bearing asphaltite deposits in Yauli province of Junin on the Altiplano.

Abundant pegmatites occur in the Pampacolca area of Arequipa in southern Peru and probably offer the best possibility for beryl. Some uranium minerals may also be present. Traces of monazite are reported in the black sands along the northern coast of Peru.

Bolivia is another richly mineralized area. The Cordillera Real on the eastern edge of the Altiplano is noted for its tin deposits, including those at Llallagua, Oruro, Potosi, Chocaya, Huanuni, and Araca. In addition to being one of the world's greatest tin producers, Bolivia is a major producer of tungsten and antimony and also a producer of silver, copper, and lead. The high temperature (hypothermal) deposits in the northern portion of the tin belt would not seem to offer a particularly favorable environment for uranium. The uranium of the Cornwall, England, tin deposits is believed to be a later and lower-temperature

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mineralization than the tin. However, the area of the mesothermal silver-tin deposits in southern Bolivia and the areas of copper and cobalt mineralization are certainly worthy of prospecting. The area to the east of the Cordillera Real in Santa Cruz has numerous pegmatites which have produced a little mica and columbite and may have some possibilities for beryl. There have been reports of monazite in some of the river placers of Bolivia.

The South American Cordillera in *Chile* comprises four major features: The Atacama Desert along the western flank of the Andes in the north where the nitrate and borax deposits are found; a coastal range; the main Andes mountain range along the Chile-Argentine border; and the Central Valley between the Coast Range and the Andes. A substantial number of primary uranium occurrences have been reported in Chile, and it is, therefore, a favorable prospecting area.

The northern half of the Chilean Andes has important deposits of copper, nitrate, and borax. The major copper deposits include the Braden deposit at Teniente, southeast of Santiago, Chuquicamata in Antofagasta, and Potrerillos in the Atacama Desert. The nitrate and borax deposits are of no interest with respect to atomic energy minerals. The coastal range contains numerous small phosphate, iron, manganese, and high-temperature copper deposits, while the foothills of the Andes on the eastern edge of the Central Valley have a variety of moderate- to low-temperature copper, silver, gold, lead, zinc, and mercury deposits. In both areas uranium in small amounts has been found associated with traces of cobalt in a granite-like rock called the Andean diorite. The volcanic rocks which cover large areas of Chile are less favorable for atomic energy minerals, although some uranium has been reported in low-temperature deposits in the volcanics.

Uranium mineralization has been reported from Tocopilla in northern Antofagasta province southward to Salamanca in southern Coquimba province. Scattered pods of pitchblende in quartz veins in diorite have been found in the Carrizal Alto district. None of these occurrences is yet of commercial importance, but all are worthy of additional investigation. Other favorable areas will undoubtedly be found by further prospecting of the Andean foothills and the coastal range.

South of Santiago, mining gives way rapidly to agriculture until the southern Chilean lake and fiord country is reached. Southern Chile is composed primarily of granitic rocks with apparently little mineralization other than some gold. It is probably not favorable for uranium, but there have been several reports of monazite in river and beach sands which suggest possibilities for thorium. Undoubtedly pegmatites also occur in the area, and these are a potential source of beryl.

The *Argentine* side of the Andes possesses the same possibilities for uranium

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as the Chilean side. The northernmost provinces of Argentina which make up part of the Peru-Bolivia-Chile-Argentina cobalt province would appear to be most favorable for primary vein-type deposits. Pitchblende occurs with cobalt in the San Santiago (Solitaria) mine in northern La Rioja. To the south in Mendoza province, secondary uranium minerals occur in the Soberania mine west of the city of Mendoza, apparently in occurrences of the oxidized type which of course may indicate primary uranium at depth, and copper-uranium deposits have been reported further south near Malargue. East of this general area, in San Luis and Cordoba, is the pegmatite area containing numerous, small uranium occurrences and from which the major beryl production has come. Additional beryl deposits may well be discovered here and to the northwest in Catamarca and La Rioja. Minor uranium also may occur in the vanadium-bearing asphaltites and shales along the eastern foothills of the Andes in southern Mendoza and in Neuquen.

Prospecting conditions along the South American Cordillera will vary from place to place. In general, climatic conditions and accessibility are better in the central part, from Peru to central Chile, which is also the most favorable area for uranium. Government regulations generally permit private prospecting and mining for atomic energy minerals.

THE ALPINE-HIMALAYAN SYSTEM

The Alpine-Himalayan mountain system is the third great mountain belt in the world, extending from Gibraltar on the west to Burma on the east. It is a much more complicated system than the North and South American cordillera, being composed of a large number of different mountain ranges and plateaus. Its major components from west to east are the Atlas Mountains of northern Morocco, Algeria, and Tunisia; the European Alps; the mountainous areas of Italy, Yugoslavia, Hungary, Greece, and the Mediterranean Islands; the Caucasus Mountains and the lesser ranges of Turkey and Iran, and the Himalaya Mountains across the north of India and Pakistan.

With the exception of the previously described deposits in the Italian Maritime Alps and the Rhodope Massif which are also a part of this mountain system, very little is known of atomic energy minerals. It is not an extensively mineralized area, although scattered mining districts of importance and numerous small mineral deposits are found along its length. On the basis of the present information, the western Haut Atlas and the Anti Atlas in southwest Morocco appear the most favorable for primary uranium vein deposits and may comprise a uranium province. Pitchblende has been found at Azegour; and brannerite, in association with cobalt, at Bou Azzer. The areas of sedimentary rocks to the northeast may have occurrences of secondary minerals. In addition, the phosphate deposits of Morocco and Algeria are among the highest in uranium con-

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tent of the North African and Middle East deposits which also occur in Tunisia, Egypt, Israel, and Jordan. Pegmatites containing beryl occur in the southern coastal area of Morocco near Agadir and have supplied some production.

Occurrences of uranium are reported in the *European Alps* in the lead-silver veins of southern Austria and suggest the possible existence of a favorable area extending southeast through the Dinaric Alps of Yugoslavia into Greece. The areas of Greece and Turkey on the edge of the Rhodope Massif and other areas of mineralization in granitic and metamorphic rocks may be favorable. The huge mountainous area east of Turkey, most of it very little prospected, may also contain deposits. Thorium is unknown in the entire area with the exception of reported occurrences of monazite on the shores of the Black and Caspian seas. Beryl occurs near the eastern end of the belt in numerous pegmatites in Afghanistan and has been reported in the Himalayas.

EAST AUSTRALIAN CORDILLERA

The East Australian Cordillera occupies a belt along the entire eastern coast of Australia including Tasmania, Victoria, and the eastern third of New South Wales on the south, and extending through the eastern third of Queensland to Cape York on the north. This area contains the noted copper deposit at Mt. Lyell and the tin deposits at Mt. Bischoff, Tasmania; the famous gold-quartz veins of the Ballarat and Bendigo districts, Victoria; similar deposits at Hill End, Hill Grove, and Hargraves, New South Wales, and at Charters Towers, Queensland; and the great Mt. Morgan gold and copper deposit near Rockhampton in Queensland. Although uranium occurrences of significance are not now known, these richly mineralized areas of the East Australian Cordillera should be thoroughly prospected. On the basis of the few specimens that have been reported, the Wolfram Camp-Herberton-Mt. Garnet area and vicinity southwest of Cairns in northern Queensland and the New England Tableland, New South Wales, may provide the best prospecting.

The East Australian Cordillera does not appear to be favorable for beryllium, but the possibility of finding additional monazite-bearing beach placers, similar to those in Tasmania, King Island, and Southern Queensland, is good.

THE APPALACHIAN MOUNTAIN SYSTEM

The Appalachian province consists of parallel plateaus, ridges, and valleys extending from Gaspé, Quebec, in the north to Alabama and Georgia in the south. It is a much older and less rugged area than the Rocky Mountain system. It has several well-known mining districts, such as the iron and zinc deposits of New York and New Jersey, the zinc deposits of Virginia, the copper deposits of Tennessee, and the iron ores of Alabama, but it is best known for its coal and oil. Many pegmatites occur in the province, particularly in New

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England, New York, Virginia, and North Carolina. These pegmatites are favorable for beryl. However, since the province has been extensively prospected for many years, the best opportunities now lie in the large, low-grade deposits that have not yet been worked for beryl, particularly in the tin-spodumene belt of the Kings Mountain area in southwestern North Carolina. Maine, New Hampshire, and Connecticut are also favorable states for beryl.

Many of the pegmatites of the Appalachian region contain unusual amounts of uranium, in pitchblende or uraninite and their alteration products, as well as in the refractory minerals. These pegmatites have long interested the mineral collectors and weekend prospectors of the eastern states but have not yet produced uranium in commercial quantities. The best known occurrences are the Ruggles mine near Rumney, New Hampshire, and the McKinney mine in the Spruce Pine district, western North Carolina. Uraninite and its alteration products also occur in scattered high-grade pockets of hornblende and biotite in gneiss near Garrison, New York, and primary uranium minerals have been found in some of the iron mines of New York and New Jersey. Uranium-bearing shales occur in the dissected plateau country along the western edge of the Appalachian province in eastern Tennessee, northern Alabama, Kentucky, and Ohio.

The stream beds of the entire eastern and central Appalachians, from the Potomac River south to Georgia, are prospecting grounds for monazite, but the better areas are the vicinities of the known deposits in Burke, McDowell, and adjacent counties of western North Carolina.

There may be possibilities for additional uranium deposits of present commercial importance similar to those near Mauch Chunk, Pennsylvania, in the folded conglomerates and sandstones of the long ridges and valleys in eastern Pennsylvania and western New Jersey, and in similar formations farther south. Several new occurrences were discovered in Hunterdon and Mercer counties, New Jersey, and Bucks County, Pennsylvania, in 1953. There is also the possibility of commercial deposits of uraninite or other primary minerals in the crystalline rocks of eastern New York, or in or near the iron or other mineral deposits of New York and New Jersey.

XV

BROAD PLAINS AREAS OF SEDIMENTARY ROCKS

The broad areas of the earth's surface so far described have met the general requirements for deposits of primary minerals. The massifs, shields, and similar areas are composed largely of crystalline rocks. The great mountain systems include, in addition, large areas of sedimentary rocks such as those of the Colorado Plateau, but these rocks are within a mountain building province—a zone of earth movement—that provided a ready source of mineralization. Since all mineralization must have originated from a primary source, these sedimentary areas were logical places for various types of deposits.

There are also large areas of the world composed largely of flat-lying sedimentary rocks which have little or no possibility for significant primary deposits but which may, in some cases, be favorable for other deposits of uranium. These are the broad plains areas of the world. Within these areas there are local mountainous areas of crystalline rocks that do have primary mineralization.

The largest and most important plains areas are those belts of Mesozoic and Tertiary sedimentary rocks that flank on the east the entire length of the North American Cordillera from the Northwest Territories of Canada to central Texas and the South American Cordillera from Venezuela to Tierra del Fuego. No uranium occurrences have been reported in the plains areas of Canada or South America, but this is very likely due to the fact that there has been practically no prospecting there. In the Great Plains of the United States, numerous occurrences have been found and commercial deposits have been discovered in South Dakota and Wyoming. Deposits of thorium and beryllium are limited to the local areas of crystalline rocks.

GREAT PLAINS OF THE UNITED STATES

The Great Plains of the United States comprise a belt 500 miles wide extending from Canada to central Texas, bounded on the west by the Rocky Mountains and on the east by a line running through about the middle of the Dakotas, Nebraska, Kansas, and Oklahoma. The Great Plains is a high, semi-arid, dry-farming and ranching area. It was elevated on the west to about 5,000 feet by the formation of the Rocky Mountains and by the deposition

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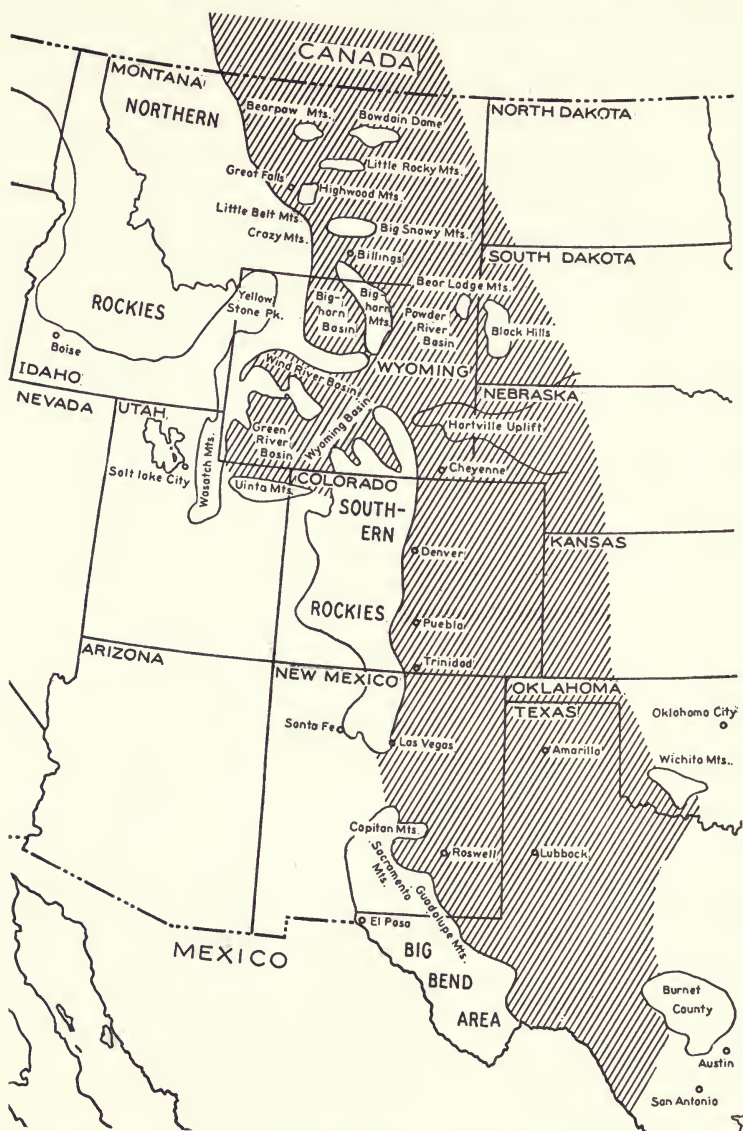


PLATE XIX. Areas of Great Plains and Adjacent Basins Favorable for Colorado Plateau-type Deposits of Uranium.

of sedimentary beds derived from the erosion of the mountains. The formations are equivalent to those that contain the deposits of the Colorado Plateau area and are possible hosts for such deposits as well as for uranium-bearing lignites, phosphates, and shales.

BROAD PLAINS AREAS OF SEDIMENTARY ROCKS

The most likely places to prospect in the Great Plains are along the edge of the Rocky Mountains and around the small mountain masses, uplifts, and folds scattered along the length of the plains and in which may have originated the uranium found in secondary minerals in some of the surrounding rocks. The mountains or uplifts themselves represent the only possibility for thorium or beryllium deposits and may have the oxidized secondary type of uranium deposit. The Silver Cliff mine on the Hartville uplift near Lusk, Wyoming, is an example of the latter.

The pegmatites of the Black Hills are the chief producers of beryl in the United States. Thorium minerals have been found in pegmatites at Barringer Hill, Burnett County, Texas, and in fluorite and iron-manganese veins with traces of uranium in the Bear Lodge Mountains near Sundance, Wyoming. The Great Plains area is of greatest interest, however, because of its possibilities for carnotite and copper-uranium deposits.

Most of the uranium deposits found so far have been carnotite deposits in sandstones on the southern, western, and northwestern flanks of the Black Hills and in the Powder River Basin, in which the Pumpkin Buttes and other carnotite deposits are located as well as a recently discovered occurrence of uranophane and carnotite in limestone. Favorable sandstone beds are also exposed on the east flank of the Black Hills, although they are thinner and the exposed belt is narrower. Minor uranium occurrences have been found in the younger (Oligocene) beds of the Bad Lands east of Rapid City. Other areas that deserve particular attention are the sedimentary rocks surrounding the Bearpaw, Highwood, Big Snowy, and Little Rocky mountains in central Montana; the Bear Lodge Mountains and Hartville uplift in Wyoming; the Capitan Mountains west of Roswell, New Mexico; the Wichita Mountains, Oklahoma; Burnett County, Texas; and the "hogback" ridges and small sedimentary embayments along the Rocky Mountain front in Colorado, southern Wyoming, and northern New Mexico. In the hogbacks, carnotite occurs in the Old Leyden coal mine near Golden, at the Mike Doyle prospect about 10 miles south of Colorado Springs, Colorado, and in a recently discovered deposit near Lyons, Colorado.

In 1952, new carnotite and copper-uranium finds were made in outcrops of sandstone of Triassic age east and north of Las Vegas, New Mexico, in San Miguel and Mora counties. This formation, known in New Mexico, Oklahoma, and Texas as the *red beds*, contains small bedded copper deposits similar in many respects to the copper-uranium deposits of the Colorado Plateau. Much prospecting remains to be done in northeastern New Mexico and northwestern Texas around the extensive outcrops of this formation and in the overlying younger sedimentary rocks.

Many flat-topped hills or *buttes* are also found in the Great Plains. Some

MINERALS FOR ATOMIC ENERGY

of these have been found to contain uranium-bearing lignite beds below the lava caps, particularly in Montana, the Dakotas, Wyoming, and New Mexico. An extensive shale formation of Cretaceous age in South Dakota, Nebraska, Kansas, and Oklahoma is also uranium-bearing at least in part.

GREAT PLAINS OF CANADA

The Great Plains of Canada extend northward from the Canadian border to the Northwest Territories, occupying a belt between the Canadian Rockies and the Canadian Shield about 600 miles wide on the south and narrowing to about 200 miles wide on the north. Although the sedimentary formations are of the same general type and age as those of the Great Plains of the United States, no uranium occurrences have yet been found in this area. The possibility of discoveries there cannot be excluded, but it is a much less favorable area for prospecting than the area to the south, for three principal reasons: (1) The adjacent Canadian Rockies are not as well mineralized as the Rocky Mountains in the United States. (2) There are no outlying mountain masses and local uplifts, caused by igneous intrusions, to provide the source of uranium and to expose the sedimentary formations around their edges. (3) Much of the area is difficult to prospect because of the thick covering of glacial debris (sand, gravel, and boulders left by the retreating ice of the Ice Age) and the heavy vegetation and soil cover.

There appears to be no possibility of significant thorium or beryllium deposits, because there are no granitic rocks or other opportunities for primary minerals.

PLAINS AREAS OF SOUTH AMERICA

The great plains areas of South America occupy a strip between the mountains of the South American Cordillera on the west and the shield areas of the Guianas and Brazil on the east. They extend from the north coast of Venezuela to southern Argentina, including parts of all the Latin American countries except the Guianas and Chile. No uranium is known in this very large area with the possible exception of some of the reported occurrences in Argentina along the flank of the Andes. This may be due to the fact that there has been practically no prospecting, for there is no reason to believe that parts of the area may not be as favorable as the Great Plains of the United States. The central portions comprising northwestern Brazil, eastern Peru and Bolivia, and northern Argentina should be favorable. As in the other great plains areas, beryllium and thorium possibilities are restricted to isolated mountainous areas of crystalline rocks.

BROAD PLAINS AREAS OF SEDIMENTARY ROCKS

OTHER SIMILAR AREAS

There are other areas in the world with some characteristics similar to those of the great plains, principally with respect to the type of sedimentary formations present. These include parts of the Great Artesian and Murray basins lying west of the East Australian Cordillera, the Eucla Basin bordering the Great Australian Bight on the south coast of Australia, the Carnarvon Basin on the central west coast, and the Canning Basin on the northwest coast. The increasing number of discoveries in the Tertiary basins of Wyoming make these areas appear more favorable than they would have been considered prior to 1952.

North-central Africa, including the interior areas of French West Africa, Libya, Egypt, and Sudan, is poorly explored, but it contains numerous local mountainous areas, uplifts, and depressions, some of which may warrant prospecting.

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OTHER AREAS OF NORTH AMERICA

There are two additional broad physiographic provinces in North America that should be mentioned briefly. They are the Central Lowlands and the Atlantic and Gulf Coastal Plains. Neither of these areas has much possibility for uranium other than the large, low-grade, bedded deposits of which each has known occurrences. Beryllium possibilities are poor in the Central Lowlands and nonexistent in the coastal plains. Monazite possibilities are reasonably good in the Atlantic Coastal Plain.

CENTRAL LOWLANDS

The Central Lowlands comprise the great central lowland area of the United States surrounding the Mississippi Valley, including parts of 20 states from central North and South Dakota, Nebraska, Kansas, Oklahoma, and Texas eastward to the Appalachian Mountain System. The rocks are for the most part older (Paleozoic), flat-lying, sedimentary formations, predominantly limestones and shales and with thick soil covers, making prospecting difficult. The same type of formations extend northward in a narrow belt between the Canadian Shield and Great Plains, connecting with the MacKenzie Lowlands and the arctic sedimentary formations on the northwest and north edges of the shield, respectively.

The St. Francis Mountains of southeast Missouri, the Arbuckle Mountains of southeast Oklahoma, and the Ozark and Ouachita mountain area of southwest Missouri, western Arkansas, and southeast Oklahoma are the only areas similar to the numerous small mountainous areas of the Great Plains. Minor occurrences of beryllium, thorium, and refractory uranium minerals have been found in Hot Springs County, Arkansas, and in other areas of the Ouachita-Ozark mountain area.

The lead-zinc mining districts of the Tri-State area of Missouri, Kansas, and Oklahoma, and the lead deposits in southeast Missouri are not known to contain any of the atomic energy minerals; nor do the manganese and bauxite deposits of Arkansas contain more than traces. Other less important mineral deposits, as well as coal deposits, in the Mississippi Valley appear to be equally unfavorable.

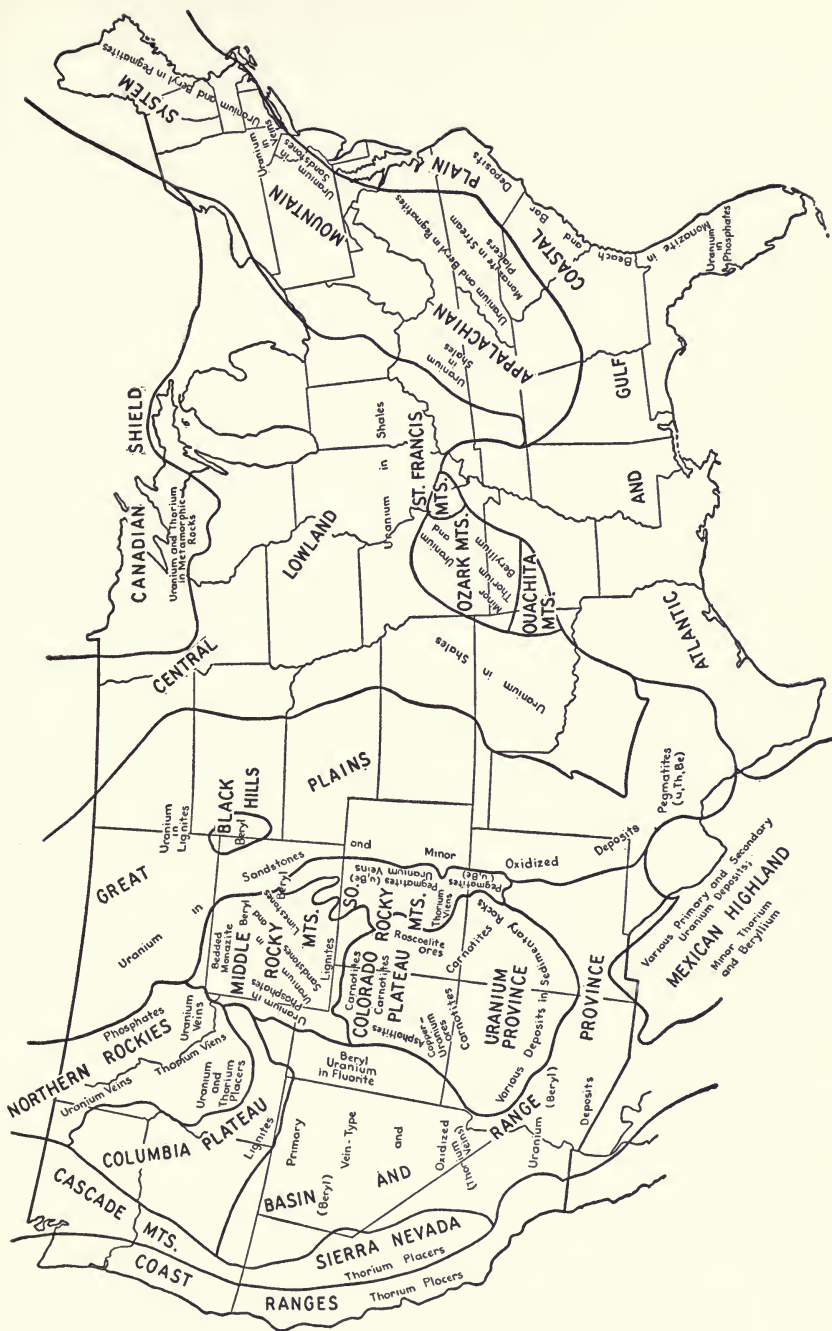


PLATE XX. Occurrences of Uranium, Thorium and Beryllium Related to Physiographic Provinces of the United States.

MINERALS FOR ATOMIC ENERGY

The Central Lowlands and the similar areas in Canada are, however, favorable places for the large, low-grade, bedded deposits of uranium in shales and phosphatic rocks. The Ohio and Albany black shales of Indiana, for instance, are similar to the Chattanooga shale and contain only slightly less uranium. Black shales in the Tulsa area of Oklahoma contain phosphate nodules with a little uranium and parts of the Woodford formation in southern Oklahoma have a uranium content similar to that of the Chattanooga shale. Large areas of black shales exist throughout the area, and other uranium-bearing formations may exist, but it is doubtful that large deposits exceeding the Chattanooga shale in uranium content will be found.

ATLANTIC AND GULF COASTAL PLAINS

The Atlantic and Gulf Coastal Plains of the United States comprise a belt of poorly consolidated, sedimentary formations from 50 to 500 miles wide, derived primarily from the erosion of the Appalachian Mountain System, extending from Cape Cod along the east and south coasts of the United States to Mexico and including all of Florida. This zone is favorable only for placer deposits of monazite and minor amounts of other refractory thorium and uranium minerals and for uranium-bearing phosphate deposits. Extensions of the uranium-bearing phosphate deposits of central Florida northward into Georgia and the Carolinas are possible.

New low-grade monazite deposits may be found along the rivers that cross the Atlantic coastal plain from Virginia south or along the Florida beaches from Melbourne north. The most interesting possibilities, however, are recently discovered monazite-ilmenite deposits on the beaches of islands along the Georgia coast and buried beach and bar deposits of heavy minerals containing monazite formed in Cretaceous and Tertiary time that exist along a 30- to 50-mile-wide coastal belt from Delaware to Florida, particularly Cretaceous and Pleistocene wave-cut terraces in southeastern South Carolina and Georgia. The ilmenite deposits at the south end of Trail Ridge in north-central Florida contain only traces of monazite, but terraces along its northward extension into Georgia and to the east may well prove to be richer. Nothing of interest is known along the Gulf coast.

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OTHER AREAS OF THE WORLD

A few areas of the world, most of which appear to have, at best, slight favorability for atomic energy minerals or of which too little is known to make a conclusive evaluation, were not included in any of the physiographic divisions of the world described in previous chapters. These areas are briefly mentioned here.

ANTARCTICA

The physiography and geology of the Antarctic continent are so little known that it is impossible to make any reasonable evaluation of the possibilities for uranium, thorium, or beryllium. Furthermore, the continent is so remote, and the climatic conditions so unfavorable, that any prospecting activities must of necessity be restricted to members of major exploratory expeditions, usually government-sponsored. No rock specimens yet collected from Antarctica have contained sufficient amounts of any metal to indicate deposits that would be commercial even in more accessible areas, and none is known to contain atomic energy minerals. Antarctica is believed to have large areas of shield characteristics, the exposed portions of which should be prospected by future expeditions.

ARABIAN PENINSULA

Much of Saudi Arabia can be included among the least explored areas of the world. Except for certain areas intensively prospected for oil, its geology is not well known. The situation in the countries immediately to the north is much the same with the exception of Israel, which has known phosphate deposits that bear examination. The most favorable parts of Arabia are probably the mountainous areas of Hejaz, Yemen, Hadhramout, and Oman, flanking the Red and Arabian seas and the gulfs of Aden and Oman. These areas are known to have a few very old mines which are believed to have produced copper and gold in the days of King Solomon. Museum specimens of turquoise from Arabia contain small amounts of uranium.

MINERALS FOR ATOMIC ENERGY

FORMOSA

Several placer areas on Formosa are known to contain monazite. Some of these deposits may approach commercial grade, and refractory uranium minerals may also be present. Such deposits are believed to be the only possibilities for atomic energy minerals with the possible exception of minor amounts of beryl in pegmatites.

ICELAND

Iceland is an area of recent volcanic activity that has no significant metal deposits and presumably has no possibilities for atomic energy minerals. It has been known to geologists primarily for its volcanoes and unusually perfect crystals of calcite from which originated the term, Iceland spar.

NEW CALEDONIA AND FIJI

The residual nickel deposits of New Caledonia are among the most important in the world. However, they have been formed in igneous rocks of high iron and magnesium content and are not considered favorable for uranium, thorium, or beryllium. No atomic energy minerals have been reported from the gold deposits of the Fiji Islands.

NEW GUINEA

New Guinea, which includes the Australian territory of Papua, is known in mining circles for its important gold placer deposits on the Bulolo River in Northeast New Guinea. These placers are a possible source of by-product monazite and refractory uranium minerals.

NEW ZEALAND

Most of the North Island and the east coast of the South Island are made up of recent volcanic rocks which are not favorable for atomic energy minerals. The gold quartz veins and coal deposits are not known to contain these minerals. The central and western part of the South Island, however, is a minor thorium province. Monazite occurs with gold and ilmenite in river and beach deposits in the Grey River basin and along the Greymouth-Cape Fowlwind coastal area of northern Westland and southern Nelson. The gold-bearing beach sands of the southern to central Westland coastal plain from Bruce Bay northward to Hokatika contain minor amounts of thorite and thorianite, including their uraniferous varieties. The possibility of richer deposits of the thorium minerals in the numerous beach and river terraces, particularly along the northern part of the west coast of South Island, cannot be excluded. The granitic and other crystalline rocks of the South Island are also favorable

OTHER AREAS OF THE WORLD

areas for pegmatites, some of which might contain beryl, although no important occurrences are known.

PHILIPPINES AND CELEBES

With the exception of the Zambales Mountains and Cordillera Central of northwestern Luzon in the Philippines, these islands are, to a large extent, volcanic with little chance for atomic energy minerals. No definite occurrences are known on Luzon, but some may exist. The Philippines have produced gold, iron, copper, and chromium, and the Celebes have gold vein deposits.

SOUTHWESTERN INDONESIA

Southwestern Sumatra, Java, Bali, Lombok, Soemba, Flores, and numerous other islands stretching from just west of Malaya to New Guinea form the outer belt of volcanic rocks in southeast Asia. Sumatra has produced some gold and silver from veins in young volcanic rocks, but this entire volcanic belt is unfavorable for atomic energy minerals. The north coast of Sumatra is part of the Malayan tin province and has monazite at numerous localities. The Mentawai Islands, Soemba and Timor, are nonvolcanic, but are not believed to offer possibilities of significant deposits.

RUSSO-CHINESE SPHERE

In discussing the potentialities of the various areas of the world, the great mass of Soviet-dominated Asia has been mentioned only briefly. Needless to say there are many areas within this sphere, particularly in Siberia and China, that have the characteristics favorable for atomic energy minerals. Since they will be of no interest to the prospector of the Free World, they are not discussed in detail. There is evidence that, although resources of atomic energy minerals in addition to the known deposits are undoubtedly present, the region is not as favorable for new discoveries as some other areas of the world.

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PART THREE

HOW TO LOOK:

PROSPECTING PREPARATION, EQUIPMENT AND
REGULATIONS, RADIOACTIVITY AND USE
OF THE COUNTER, EVALUATION AND
AID, PRICES AND MARKETS

XVIII

INTRODUCTION

The foregoing chapters describe the most favorable areas for prospecting and what types of deposits might be found there, as well as evaluate the less favorable areas. Nevertheless, when it comes down to actually starting out, there is quite a wide choice of specific locations within large favorable areas. To help the prospector solve this problem within the United States, the Atomic Energy Commission provides certain information which is available at all field offices of the Commission's Division of Raw Materials, in many U. S. Geological Survey and U. S. Bureau of Mines offices, and at certain state agencies and public libraries.

The Commission publicly announces the location of areas of unusual radioactivity discovered by its aerial radioactivity surveys and surface investigations throughout the United States. Maps showing these localities are posted on the fifteenth day of each month or the first day of business thereafter at A.E.C. and U.S.G.S. offices listed in Appendix VII.¹

The Atomic Energy Commission and the U. S. Geological Survey also make available for inspection in their various offices, and in a number of libraries, copies of reports written by their staffs and by contractors covering the results of exploration and laboratory work. These reports may be seen at locations listed in Appendix VII. A number of these reports are available for sale and others may be had free of charge. Lists may be obtained by writing the Office of Technical Services, Department of Commerce, Washington 25, D. C., and the U. S. Geological Survey, Washington 25, D. C.

As a further aid to the prospector, the staffs of the field offices of the Commission, as well as of the Geological Survey and Bureau of Mines, are always willing to discuss prospecting and exploration problems with the prospector and to provide whatever help they can.

In approaching the problem of how to look for minerals for atomic energy, the prospector will find that he is faced with four general considerations, all but one of which are involved in prospecting for any mineral. The exception,

¹ The U.S.G.S. makes available the results of its aerial radioactivity surveys at offices in the vicinity of the area covered and at its offices in Washington, D. C., Denver, Colo., Grand Junction, Colo., Salt Lake City, Utah, and San Francisco, Calif.

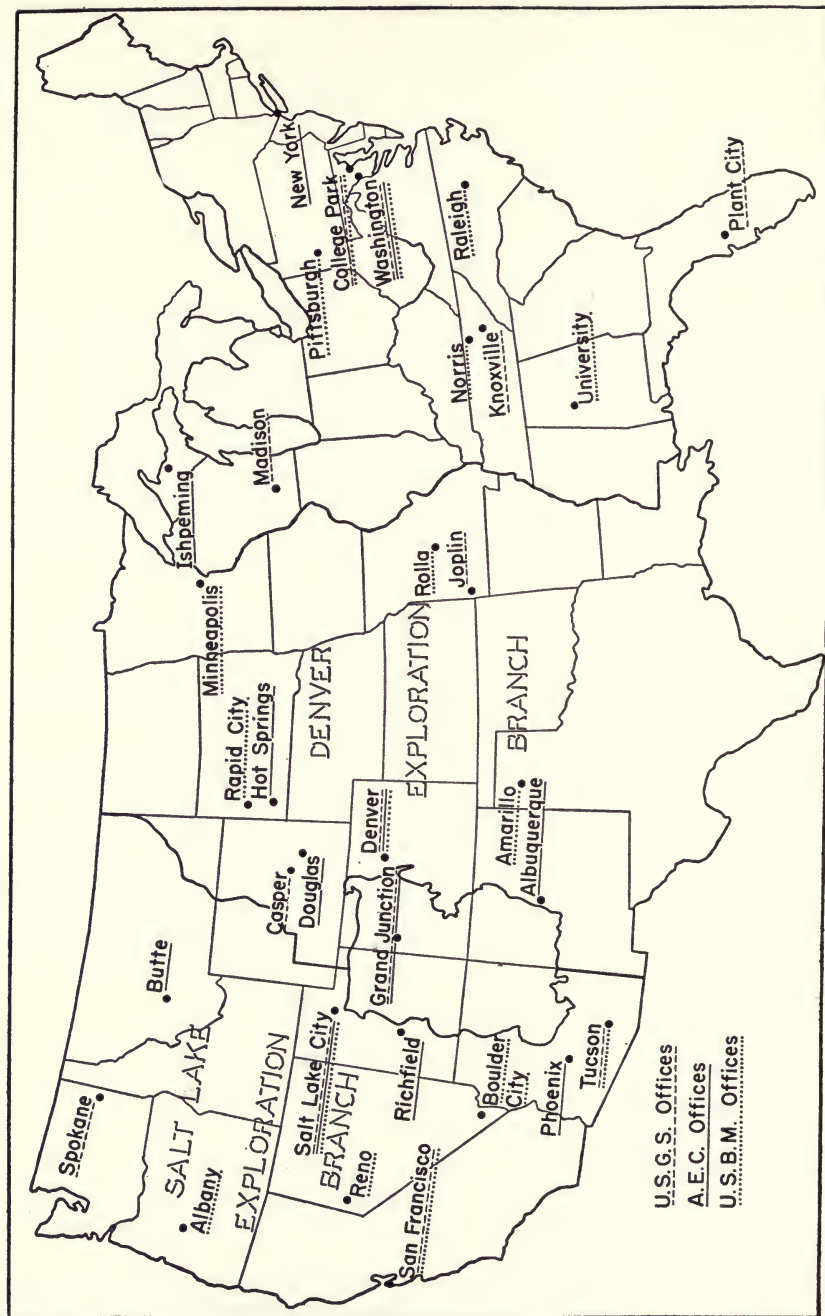


PLATE XXI. Atomic Energy Commission Exploration Program. Courtesy U. S. Atomic Energy Commission.

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of course, is the use of various types of equipment specifically designed for the identification of radioactive minerals by the detection of radioactivity. Otherwise, there is nothing particularly unusual about prospecting for these minerals. The amateur and professional prospector, the mining geologist and the engineer, all use the same basic rules and procedures for prospecting for and evaluating deposits of gold, copper, lead, etc.

The first consideration is the type of preparation and standard equipment required and an understanding of regulations governing prospecting. The second is the understanding and use of the special equipment for measuring the radioactivity which is unique to prospecting for uranium and thorium. The third involves the accepted practices for determining the importance of a find after it is made, with particular reference to special factors applicable to uranium, thorium, and beryllium. The fourth and last concerns what to do with a find after discovery and evaluation.

PREPARATION AND EQUIPMENT

The preparation and equipment required for successful prospecting may be divided into two parts: That required to maintain the prospector in the field and that required to do the job once there. Obviously both of these vary within wide limits depending upon the type of prospecting and the area in which it is to be done. With respect to the first, the Sunday or weekend prospector and mineral collector normally require little more than their usual means of transportation—car, horseback, or foot—the standard picnic basket or box lunch, and perhaps a road map. Those wishing to stay out a little longer and “rough it” a bit more require a tent or sleeping bag and the usual camping equipment. The semi-professional or professional prospector will require preparation and equipment varying from camping equipment sufficient for a few days to several weeks away from civilization in the United States to the mounting of a major exploring expedition abroad. The details of such preparations are not the proper subject of this book, and the reader inexperienced in the subject, who wishes to undertake extensive prospecting expeditions, is referred to the many books on the subject. A word of warning, however, even to the less ambitious prospectors: Although it is possible to cover a great deal of relatively untraveled, favorable prospecting ground throughout the western United States by automobile, no one should undertake even that type of activity, particularly in the Colorado Plateau area and the southwestern United States in general, without taking these basic precautions:

1. Make certain the automobile has been recently inspected and is in good condition.
2. Obtain a *second* spare tire, a tire and tube repair kit and pump, and extra supplies of water, oil, gasoline, and food.

3. Put a good set of tire chains and a shovel in the car.
4. Have a good road map and verify the information on it with a recent traveler in the area.
5. Make certain through inquiry whether an ordinary passenger car can travel the roads or whether a truck or four-wheel-drive vehicle is required.
6. Inquire as to weather expectations in the area and the effect of a weather change on road conditions.
7. Have a good first-aid kit, including equipment for treating rattlesnake bites.

Having made the necessary preparations for maintaining himself in the field, the prospector must consider the equipment required to perform the actual prospecting. Here again the amount and type of equipment will vary widely. Almost any prospector for radioactive minerals will want at least an inexpensive *counter* to measure radioactivity, and many amateurs make this their only piece of equipment. The selection and use of counters will be discussed in detail in the following chapter.

The amateur prospector will find some additional minimum equipment helpful, and the professional prospector should not be without it:

1. *Geologic pick*: A short-handled tool with a square hammer-face on one end of the head and a pick point on the other end. Useful for knocking off or prying loose rock or mineral specimens from outcrops.
2. *Knife*: The hardness of minerals can be determined by scratching the surface with a pocket knife. This is a useful aid to identification.
3. *Streak Plate*: A small rectangular porcelain plate upon which the color of the powder of a mineral (streak) may be demonstrated—a further aid to identification, obtainable from any mineral dealer.
4. *Magnet*: A small, strong, permanent magnet is useful for testing minerals and for separating magnetic mineral grains from nonmagnetic material. For example, magnetite, which often makes up a large fraction of the heavy mineral concentrate from a placer deposit, can easily be separated from the monazite, zircon, and other nonmagnetic minerals present. Wrapping the end of the magnet in wax paper or a cloth while making the separation will save time in removing the magnetic material from the magnet.

5. A supply of small cloth *sample sacks* for samples and specimens.
6. A small *notebook and a pencil* for recording observations of interest.

For the prospector who can afford them and who wants to be completely equipped, the following items are also useful:

1. *Prospector's pan*: A heavy, shallow, circular pan, usually used in panning gold but useful as well in separating out heavy minerals from placer sands or from the crushed rock of an outcrop. Shaking a sample with water with a cir-

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cular motion causes the heavier minerals to settle to the bottom of the pan and the lighter, and usually valueless ones, to be washed off the top. By repeating this procedure the heavy minerals can be concentrated and identified. Rough approximations of the percentage content of the desired minerals in the deposit can also be made. For this purpose, of course, a measured amount of original material must be used.

2. A small cast-iron *mortar* or pot with *pestle* for crushing rock samples.

3. A *pocket lens* for close examination of mineral specimens.

4. A *Brunton* or other pocket compass for rough map making and for determining the inclination (dip) and direction (strike) of rock outcrops.

5. A miner's *pick, shovel, moil* (or other sharp chisel-like instrument), and small *sledge hammer* or "single jack," for taking samples, and a small *piece of canvas* for collecting them.

6. A portable *ultraviolet lamp* for identifying the presence of fluorescent minerals.¹

7. A small *iron or platinum wire*, an *alcohol lamp* or *Bunsen burner*, and small bottles of *sodium fluoride, lithium fluoride, borax*, and *salt of phosphorus* (microcosmic salt), for making the *bead test* for uranium and other identifications (see Appendix III).

An indispensable part of any prospecting venture is a good map. Although road maps are helpful, the careful prospector will attempt to find something better and more detailed. The most readily available and, generally, the best maps for this purpose are the topographic maps published by the U. S. Geological Survey. They are available for about half of the United States, and those covering a particular section of the country can usually be obtained for a few cents in the map, book, or stationery stores of the local towns. They are often referred to as "U.S.G.S. topo sheets" or "quadrangle maps." Index Map Circulares, showing those parts of individual states for which maps are available, can be obtained without charge from the U. S. Geological Survey, Washington 25, D. C. For those who wish more technical information, the U. S. Geological Survey also publishes geologic² and mineral maps. These maps are listed in a

¹ Some minerals will glow or "fluoresce" under the stimulus of ultraviolet light, and this can be used as a means of identification. Portable battery-operated lamps producing ultraviolet light are manufactured by a number of companies and sold at a cost of \$15 to \$25. They are often helpful in showing the distribution and concentration of uranium minerals in a vein or other deposit. Their use is limited because only a few of the uranium minerals, and none of the thorium and beryllium minerals, fluoresce. Furthermore, many other minerals, such as calcite, scheelite, fluorite, willemite, and zinkite, do fluoresce. This method has probably had more use in prospecting for scheelite (a tungsten mineral) than for any other mineral. Most lamps must be used at night, under a blanket, or in dark mine workings. However, an instrument that can be operated in daylight has recently been placed on the market at a cost of about \$75.

² Preliminary *photogeologic* maps of some areas prepared by the U.S.G.S. can be purchased from Dunkin Blueprint Company, Grand Junction, Colorado.

MINERALS FOR ATOMIC ENERGY

booklet, obtainable free of charge, entitled "Publications of the Geological Survey," which also lists all of the Survey's geological and mining publications.

REGULATIONS GOVERNING PROSPECTING

Another important thing that must be considered in the preparation for prospecting is where one can prospect, that is, what the regulations or restrictions concerning prospecting are. In the United States, the prospector is concerned with two types of landholding—public and private. Permission must be obtained from the landowner to prospect private land. In the eastern United States most of the land is privately owned and there is usually obvious evidence of ownership, such as cultivation, fences, gates, or notices forbidding trespassing. In the eleven western states¹ 54 per cent of the land is publicly owned, and evidence of private ownership where it exists may be missing. There the prospector should be on the lookout for cairns (rock piles), stakes, markings on trees, claim notices, prospecting pits, tunnels, and other indications that a claim has been staked on public land.

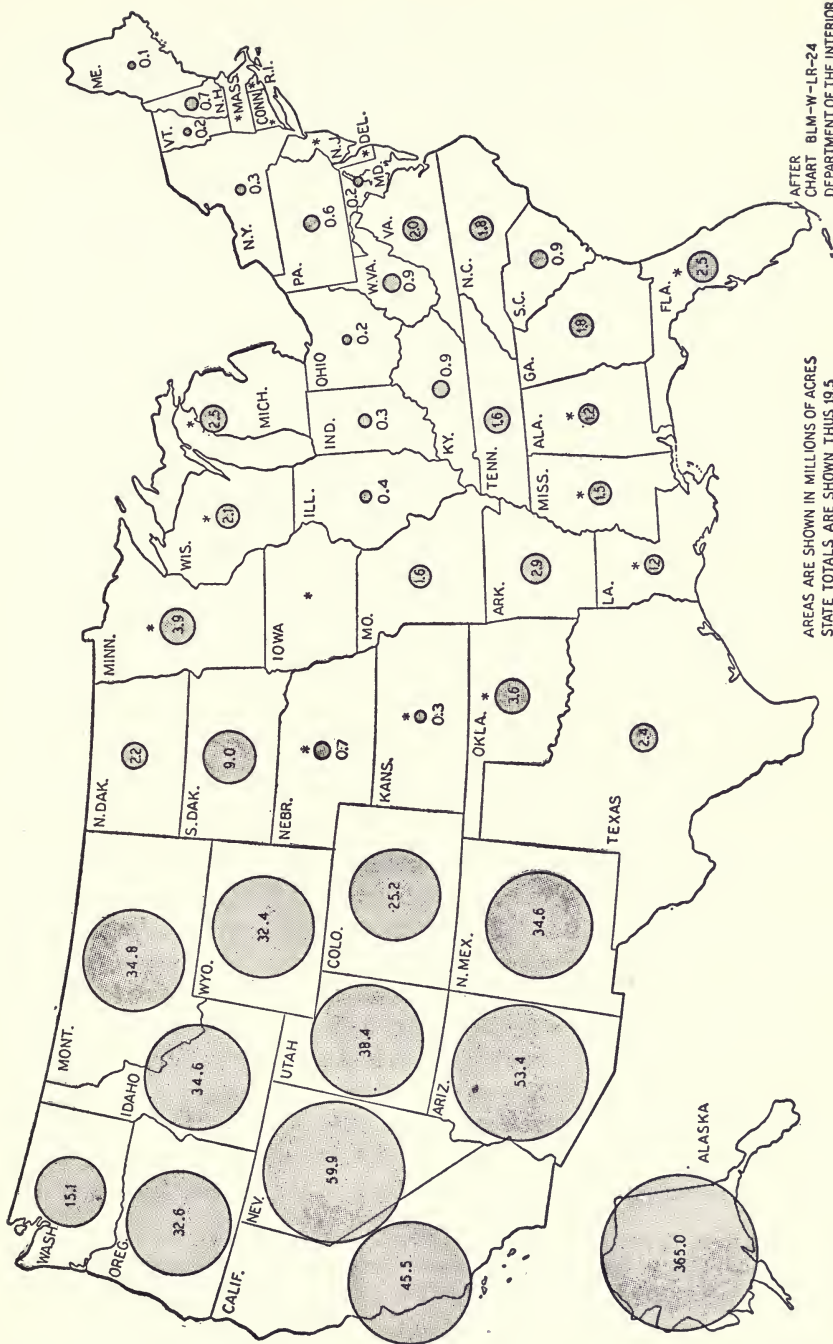
When prospecting on private ground, it is obviously to the prospector's best interest to locate the owner to obtain his permission and to obtain an understanding or written agreement with him concerning the purpose of the prospecting and the disposition of any valuable minerals that may be found. For, in addition to keeping out of trouble, unless the prospector is interested only in mineral collection, any discovery will be of no value to him without such an arrangement.

There are no special laws or restrictions concerning prospecting for atomic energy minerals in the United States. The provisions of the Atomic Energy Act of August 1, 1946, providing for the control of uranium and thorium through licensing, apply only to the sale or transfer of those metals or their ores after they have been removed from the ground, and do not interfere with normal prospecting and mining activity.² The federal and state laws which apply to prospecting on public lands for ores and minerals, in general, apply also to uranium, thorium, and beryllium ores.

No government license or other form of government permission is needed for prospecting for uranium, thorium, or beryllium on either public or private lands except such places as Indian reservations and national parks, or monuments. Permission of the state government concerned should be obtained for prospecting on lands which are known to be state owned. All Indian reservations, with the exception of the Papago Indian Reservation in southern Arizona, require permits for prospecting from the superintendent of the reservation.

¹ Approximately 89 per cent of the publicly owned land in the United States is located in the eleven western states.

² The licensing regulations are printed in Appendix IX.



MINERALS FOR ATOMIC ENERGY

If a discovery is made on Indian land, an application for a lease may be made to the Bureau of Indian Affairs, Department of the Interior, Washington 25, D. C., through the local representative.¹ In the case of the Papago Reservation, if a claim is staked, the superintendent must be furnished a copy of the location notice, within 90 days after filing in the normal procedure.

Regulations and procedures concerning the staking of claims for uranium, thorium, and beryllium in the United States are also the same as for any other metal. These laws, however, can become very complicated in their application, and thorough inquiry should be made at the nearest District Land Office of the Department of the Interior by those inexperienced in the problem. States containing public lands on which claims can be staked are Arizona, California, Colorado, Florida, Idaho, Louisiana, Mississippi, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oregon, South Dakota, Utah, Washington, and Wyoming. The same holds true for Alaska. Circular No. 1278 (1935) of the Bureau of Land Management, Department of the Interior, which gives information concerning mining claims, and a statement by the U. S. Atomic Energy Commission concerning uranium and thorium are reprinted in Appendix IX.

Most national forests are open to prospecting, but a check should be made at the nearest Field Office of the U. S. Forest Service to make sure that a particular forest is not one of the few restricted from the staking of mineral claims by the act of March 1, 1911, known as the Weeks Act. Mt. McKinley National Park and Glacial Bay National Monument in Alaska, Organ Pipe Cactus National Monument in Arizona, and Death Valley National Monument in California are the only national parks or monuments open to prospecting and the staking of claims.²

There is one other restriction to be considered: The Atomic Energy Commission from time to time requests the Department of the Interior to withdraw the right of claim staking in small areas, so far confined to Utah, Colorado, New Mexico, and Wyoming, in order to undertake government exploration projects. Most of this land is released as soon as exploration is completed, and the total area withdrawn at any one time has never exceeded a few hundred square miles. The announcement of these withdrawals is made through public notices issued by the local office of the Bureau of Land Management of the Department of the Interior. The land on which uranium deposits are discovered as a result of these government exploration programs remains withdrawn and is leased

¹ Additional information on the Navajo Indian Reservation, Arizona, is given in Appendix IX.

² A license to prospect for and mine uranium ores in the Capitol Reef National Monument in Wayne County, Utah, can be obtained under certain circumstances from the Atomic Energy Commission by application to its Grand Junction Operations Office, Grand Junction, Colorado.

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to private interests for development and mining by the Commission's Grand Junction Operations Office, Grand Junction, Colorado.

PROSPECTING IN OTHER COUNTRIES

Regulations governing prospecting and mining in general, and specific laws concerning atomic energy minerals, vary widely throughout the world. In some countries private prospecting, especially for radioactive minerals, is forbidden or made practically impossible by complicated laws and decrees, while in others the situation is little different from prospecting in the United States. There has been an encouraging trend recently, particularly in Latin America, to modify restrictive legislation. Available information on prospecting in Australia, Canada, and the United Kingdom is summarized in the Appendices. Prospectors interested in other countries should inquire at the nearest consulate of the country in question or write directly to the Department of Mines in the capital city or to the organizations listed for certain countries in Appendix XV.

A license is required to take or send a counter out of the United States. Application should be made to the U. S. Atomic Energy Commission, 1901 Constitution Ave., N.W., Washington 25, D. C., Attention: Licensing Controls Branch.

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XIX

RADIOACTIVITY AND ITS DETECTION

Prospecting for uranium and thorium minerals has one major advantage over prospecting for other minerals. The most important single characteristic of these minerals, and one not possessed by any other mineral of value, is their consistent radioactivity. All uranium and thorium minerals emit certain particles or rays called *radiations*, which cannot be seen or felt, but which can easily be detected with the proper equipment, thus providing a very handy means of revealing their presence in the field. Although the radiations of thorium minerals are different from those of uranium minerals, it is difficult to tell one from the other in the field. However, knowing that one or the other occurs in a given spot is a big help in prospecting, and the prospector's knowledge of the various minerals and their manner of occurrence, or chemical analyses of samples, will tell him whether he is dealing with uranium or thorium.

Beryllium minerals are not radioactive. However, some experimental work based on the nuclear properties of beryllium has been done on the identification and assaying of beryllium minerals through the use of an artificial source of radiation. This is a complex process that has not been put to general use and has not been developed to the point where it would be practical in the field. For the present, therefore, the prospector for beryllium minerals will have to continue to rely on the time-honored prospecting methods used for the non-radioactive minerals.

Before beginning a discussion of what radioactivity *is*, it would be well to say a little about what radiation is *not*, in view of the many misconceptions about it. Radiation cannot be seen under any circumstances. It does not cause things to glow in the dark. The fluorescence of some uranium minerals in ultra-violet light is an entirely different property shared by many nonradioactive minerals. Radiation has no magnetic effect. It will not affect a magnetometer, compass, or watch, as some people have reported. Natural radiation from uranium or thorium in the rocks of the earth's crust has no apparent effect on plant or animal life. It does not cause plants to die or animals to become sick, as has also been reported. Lastly, direct radiation from uranium or thorium in naturally occurring deposits has no effect, either good or bad, on human beings. However, breathing air contaminated with radon gas or radio-

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active dust derived from uranium or thorium deposits can be detrimental under certain conditions. If, in examining a mine, the prospector encounters high radon or dust concentrations evidenced by a very high reading on his counter irrespective of its distance from the tunnel face or wall or in the exhaust air from the workings, he should avoid prolonged stays in the unventilated portions of the mine.

Uranium and thorium themselves do not actually contribute much of the radiation that comes from their minerals. Most of the radiation comes from a number of other elements derived from the radioactive decay of uranium and thorium. The uranium in uranium minerals is made up of two types of atoms—uranium-238 and uranium-235—as well as a very minute amount of uranium-234, uranium-238 being 140 times more abundant than uranium-235. When an atom of uranium-238 disintegrates, it forms an atom of another radioactive element, in this case, thorium-234. Thorium-234 then decays to form protactinium-234 and so on through a series of 13 radioactive elements known as *daughter elements* and including radium and radon, a gas, until finally an inactive element, lead, is formed.

The uranium-238 series is one of three naturally occurring radioactive series, two of which begin with uranium-238 and -235 and one of which begins with thorium, and which together have 38 elements. The thorium series is similar to the uranium series.

These other elements are not of interest to the prospector, however, since they are present in very minute amounts which cannot be seen and are of no commercial value to him. Although radium is very valuable, no payment is made for the radium content of uranium ores. Only from relatively rich ores can the radium be extracted profitably. This is done now only in the case of the ores from the Shinkolobwe mine in the Belgian Congo.

There are three types of radiation from uranium and thorium and their daughter elements. These are *alpha particles*, *beta particles*, and *gamma rays* and are referred to as *alpha*, *beta*, and *gamma radiation*. Alpha radiation has practically no penetrating power, and its effect is limited to the area immediately surrounding its source. A few sheets of paper or a few inches of air will effectively stop it, and it is therefore utilized only in laboratory studies or in very delicate prospecting techniques not normally helpful to the average prospector. Beta radiation has a greater penetration ability but is still absorbed by a sheet of tin or a foot or so of air. Most field techniques for detecting and measuring radioactivity, however, provide for beta radiation which provides a more accurate measure of relative amounts of radioactivity than the third type, gamma radiation. Gamma rays have a much higher penetrating power and are very similar to X-rays. There are various strengths of gamma rays, but the gamma radiation from uranium and thorium ores can be stopped by about

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3 inches of lead, 1 foot of rock, $2\frac{1}{2}$ feet of water, or several hundred feet of air. This means that it is quite easy to detect the gamma radiation from uranium or thorium on the ground or in the air, so long as the minerals are no more than a foot or so below the surface of the ground.

RADIOACTIVE EQUILIBRIUM

Just detecting the presence of radioactivity is, in itself, of course, a great help in prospecting for uranium and thorium. However, it has been the aim of the scientists and engineers who are continually making improved instruments for radiation detection, and the geologists who use them in the field, to come closer and closer to determining from the radiation the actual amount of uranium and thorium present in the sample or rock outcrop being examined.

Although the amount of radioactivity may be a measure of the amount of uranium or thorium in a sample, without very complicated laboratory apparatus, visual or some means other than radiation must be used to determine whether uranium or thorium is causing the radioactivity. If this is known, the amount of radiation from a known or *standard sample* of uranium or thorium—one in which the amount of uranium or thorium has been determined by chemical analysis—can be compared with the radiation from the same amount of material from an unknown sample and thus the amount of uranium or thorium in the unknown sample can be determined—if the unknown sample is in *equilibrium*. The problem of equilibrium arises because the radiation measured does not come primarily from the uranium or thorium but from its daughter elements. When a radioactive ore is in equilibrium, a certain relative proportion of each daughter element is present, no matter what the grade of the ore, and there is a *theoretical* level of radiation for a given amount of uranium or thorium. Under these conditions the amount of radioactivity measured is directly dependent upon the amount of uranium or thorium present and provides a reliable indication of the grade of the ore.

However, particularly in the case of uranium, the minerals encountered by the prospector are often not in equilibrium. This is because they have been subjected to chemical processes during which the uranium has become separated from its daughter products and insufficient time has elapsed to restore equilibrium through the process of radiation, decay, and formation of new elements in the proper balanced proportions.¹

¹When uranium or thorium is separated from its radioactive daughter elements, it immediately starts to decay and re-form them. Gradually over a period of about a million years, all of the elements in the decay series have accumulated again to the original proportions. That is, each element is present in an amount so that it decays into the element below it in the series at the same rate as it is produced from the element above it, and thereafter no further change takes place in the quantity of any of the daughter elements unless the minerals are again subjected to chemical change.

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The most important cause of a lack of equilibrium is attack by solutions such as ground waters which dissolve primary minerals and redeposit secondary minerals. For this reason, the level of radiation from uranium deposits containing a large percentage of secondary minerals is often misleading as to the actual uranium content. This is not usually a problem with thorium, since the primary thorium minerals are not readily affected by weathering and significant secondary deposition does not occur.

Inequilibrium due to weathering and oxidation of outcropping uranium deposits is especially likely when the deposits contain pitchblende and sulfide minerals such as pyrite, chalcocite, and chalcopyrite. This is true, for example, of the copper-uranium deposits of southern Utah and the primary vein deposits at Marysvale, Utah. The weathering of pitchblende-sulfide ore results in acid ground water due to the formation of sulfuric acid from the sulfide minerals. Uranium is soluble in acid waters and tends to be removed by solution, but radium is much less soluble and its compounds tend to remain behind in the weathered outcrop. Therefore, the outcrop may be radioactive due to the presence of some of the daughter elements, even though much of the uranium has been removed. As a result, a sample taken from the outcrop may give a high counter reading, but a chemical analysis will show that the uranium content is low.

The uranium removed by ground water may be redeposited as secondary uranium minerals, and many such deposits are out of equilibrium. The equilibrium conditions usually vary widely from sample to sample, and counter readings are apt to be quite misleading. There will be a lack of equilibrium in these deposits when the minerals are younger than the time required to re-establish equilibrium and the daughter elements have not yet accumulated in their equilibrium amounts. In such cases more uranium may be present than is suggested by the counter readings.

Most of the carnotite deposits of the Colorado Plateau are old enough for equilibrium to have been established. Some of them, however, have been recently attacked by ground waters causing some removal of uranium, but not as much as often occurs in deposits of primary minerals. In other cases, redeposition has occurred recently and the uranium content may be higher than the amount of radioactivity would indicate.

To summarize: the amount of radioactivity can be used as a measure of either uranium or thorium in a deposit *if it is in equilibrium*. Primary minerals that have not been attacked by ground waters are usually in equilibrium. Thorium minerals are never attacked significantly by ground waters. Primary uranium minerals near the outcrop are likely to be leached of uranium and give a higher reaction on a counter than they should. Newly formed deposits of secondary uranium minerals are apt to be too young for equilibrium and give a

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lower reaction than the amount of uranium present would indicate. Carnotite deposits of the Colorado Plateau type may be out of equilibrium either way but normally not as much as other deposits of secondary minerals or leached deposits of primary minerals.

Movement of radon, one of the daughter elements of uranium, is another cause of inequilibrium, but it is much less important. Since radon is a gas and is very soluble in water, it can move about easily through the open spaces in rocks. The effects of radon are most noticeable in confined spaces, such as mine workings and tunnels, where it accumulates and increases the measurable activity.

COUNTERS

By far the most widely used instruments for detecting radioactivity in both the field and the laboratory are *Geiger* and *scintillation counters*. Instruments of either type may vary widely in size, shape, weight, and cost, often dependent upon the make and the particular use for which they were manufactured.

Geiger Counter. The Geiger-Mueller counter, as it is officially named after two German scientists who first demonstrated the method, was developed in 1928 for laboratory measurements of radioactivity.

The first portable prospecting instruments were developed during the war and were awkward and unreliable, but now numerous lightweight, portable models are available for prospecting at a wide variety of prices. In addition, other very efficient counters have been designed for specific jobs, such as prospecting from the air, probing drill holes, monitoring mill feeds, automatically checking laboratory samples, tracing isotopes in medical treatment and research, and civilian defense.

The basic part of the Geiger counter is the Geiger or Geiger-Mueller tube. It is made of glass or metal and may have a variety of sizes from a few inches to several feet in length and from less than an inch to several inches in diameter. The tube is filled with a gas, such as helium, argon, or krypton, and a high voltage is applied between a metal wire running the length of the tube in the center and the tube wall. When the tube of a Geiger counter is placed near a source of radioactivity, some of the radiations penetrate it and produce pulses of electric current. Alpha particles are stopped by the tube wall. Beta particles have a greater penetrating power, and some of these can enter the thin wall of the tube. Gamma rays penetrate the walls of the tube in much greater numbers. A few of these rays collide with a molecule of the enclosed gas and produce charged particles, some of which are attracted toward the charged center wire and produce the electrical pulse.

In addition to the tube, a Geiger counter must have a power supply, which consists of batteries in the portable instrument, an amplifier to strengthen the

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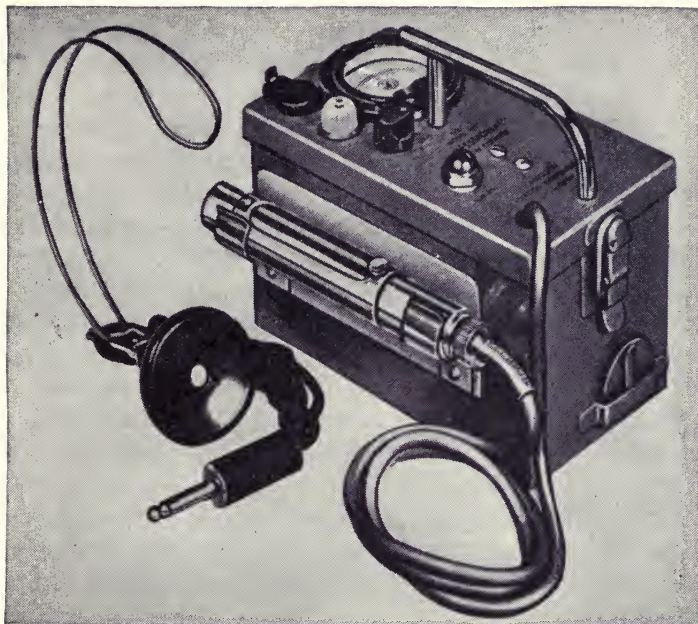


PLATE XXIII. Portable Geiger Counters. *Courtesy Sears Roebuck and Co.*

pulse, and one or more types of pulse indicator—a neon light which is caused to flash by the pulse, earphones which produce an audible “click,” or a meter like an ammeter, the deflection of the needle indicating the frequency of the pulses. The light and earphones give an individual signal each time the Geiger tube discharges and must be counted to determine the number of pulses per minute, indicating the degree of radioactivity, whereas the meter shows the average rate of radioactivity at any given time and is therefore often called a *rate meter*.

Most Geiger counters have jacks into which a headset can be plugged and in addition have either the light or the meter. Neon lights are usually found in less expensive counters, and meters on more costly models. Geiger counters equipped for prospecting also usually have a carrying case and shoulder strap, a steel probe enclosing the tube and attached to the main unit by 2 or 3 feet of cable or insulated wire, and a control for adjusting the sensitivity. There is also usually an opening or window in the steel probe protected by a sliding panel that can be withdrawn to expose the tube and permit the recording of beta radiation.

Scintillation Counters. Scintillation counters, like Geiger counters, were first developed for very sensitive laboratory use, and they have only recently been manufactured in small enough units to make a satisfactory prospecting instrument. Although they are more expensive than Geiger counters, and therefore in the minority among portable counters now in use, it is probably safe to say that they will eventually largely replace the Geiger counter in the field.

The scintillation field counter, like the Geiger, records principally gamma rays, but it depends upon their ability to produce tiny flecks of light (*scintillations*) in certain crystals, such as sodium or potassium iodide, called *phosphors*, rather than upon their ionizing effect upon gases contained within the Geiger tube.

The arrangement of the parts is similar to that of the Geiger counter. In place of the Geiger tube, a scintillation counter has the small crystal, or phosphor, attached to the end of a light-sensitive *photomultiplier tube*, and both are sealed in a unit which is often arranged for use as a probe. The scintillations produced in the crystal are transmitted as electrical pulses by the photomultiplier tube to an amplifier and passed on to a recording meter in the same manner as in the Geiger counter. Blinking lights and earphones are not used with scintillation counters.

The chief advantage of the scintillation counter is its much greater sensitivity due to the fact that the crystal reacts to a much larger proportion of the gamma rays than does the Geiger tube. Depending on the type and size of the crystal, scintillations may be produced by 50 per cent or more of the gamma rays that strike the crystal, whereas most Geiger tubes react to less than 1 per cent of the rays penetrating them.

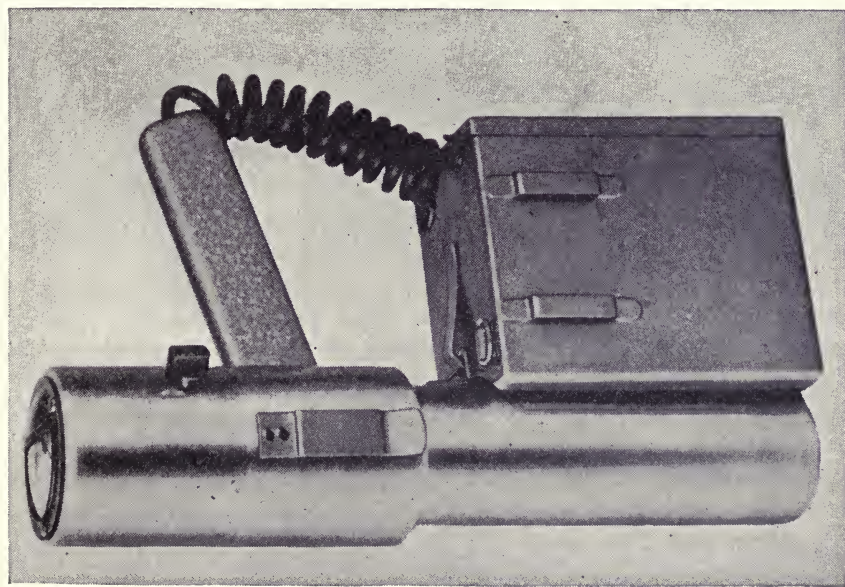
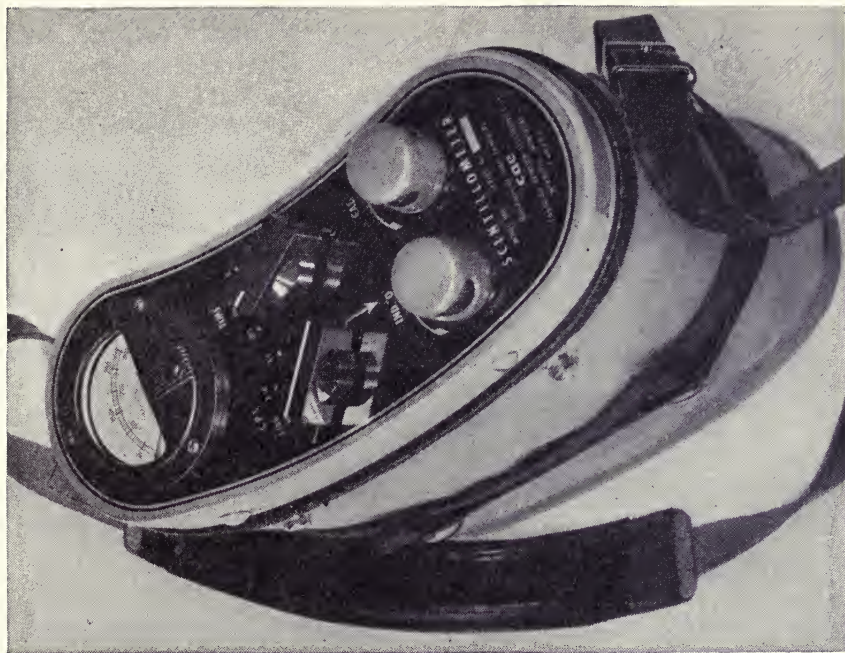


PLATE XXIV. Portable Scintillation Counters. Courtesy Radiac Corp.

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This means that the scintillation counter can accurately detect a much smaller change in amount of radioactivity; it will also produce a much more noticeable reaction to very low radioactivity or will react at a greater distance from the source. This ability is an added advantage to geologists interested in making detailed surveys of slight variations in radioactivity on the surface of the ground or in mine workings, as a means of determining possible clues to deposits that do not give more obvious indications. It is not so important to the average prospector and, in fact, may actually be a liability in underground examination where the *mass effect*, which will be discussed later, may result in such high readings that it is difficult to detect the variations in radioactivity. However, nearly all counters now being manufactured for use in prospecting by aircraft or for probing drill holes, where sensitivity is very important, are of the scintillation type. Most laboratory counters used for sample examination and analysis in conjunction with prospecting programs, however, are of the Geiger type. The laboratory Geiger counter attains its accuracy in detecting minute changes in radioactivity by measuring under controlled conditions not possible in the field.

OTHER MEANS OF RADIATION DETECTION

There are several methods of detecting radiation from uranium and thorium and their decay products which are not of any particular use to the prospector because their results are hard to evaluate or they are awkward to handle in the field. However, since they have been so widely advertised in literature on the subject, and since they will determine whether a sample is radioactive, they are described briefly here.

Photographic Test. Radiations from uranium or thorium minerals will blacken an unexposed photographic film in the same manner as sunlight. When an unexposed film or plate is wrapped in light-proof paper to prevent light exposure and placed in contact with a rock or mineral specimen that is radioactive, the radiation will expose the film. Under proper conditions, the distribution of the radioactive portions of the specimen can be recorded on the developed film as an aid to mineral identification. The picture produced is called a *radiograph*. A metal object placed between the specimen and the film or plate will absorb most of the radiation leaving an unexposed "shadow." The sharpness of the image and the time required to produce it can be used as a measure of the amount of radiation, which in turn is a very rough measure of the amount of uranium or thorium in the sample if it is in equilibrium. A specimen of pitchblende will produce a clear image in 24 hours, but a run-of-mine piece of carnotite ore will probably require several days.

Scintillation Test. Radiation striking a screen coated with zinc sulfide powder will produce bright flashes or sparks of light called *scintillations* as it

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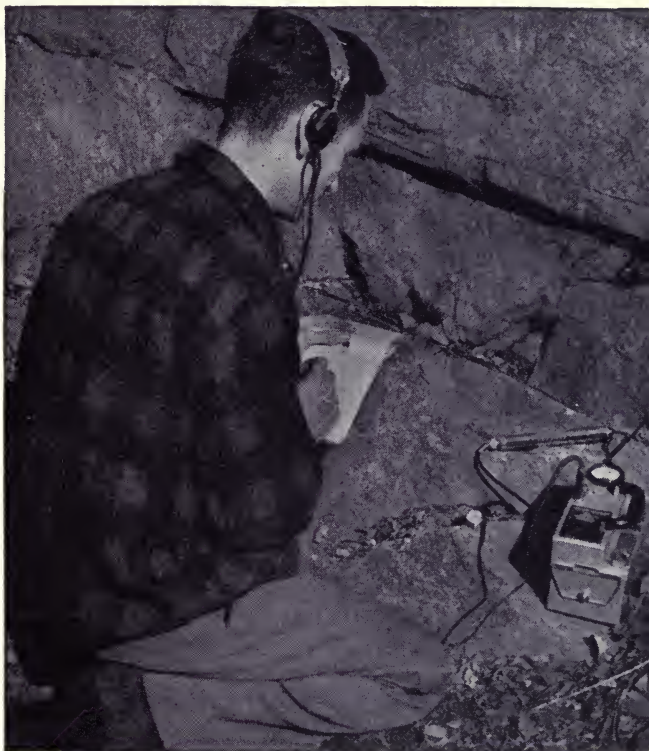
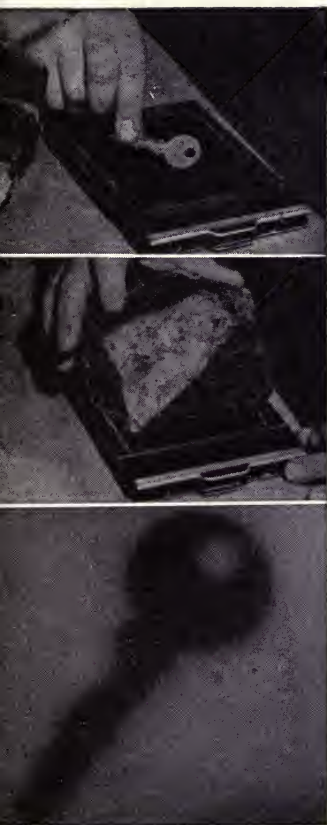


PLATE XXV. (*left*) The technique for making a photographic test for radioactivity is illustrated here. At top, a key is placed on an unexposed photographic plate. Center, a rock sample is placed on top of the key. If the sample is primarily pitchblende, the developed film will produce a picture similar to that below after a 24-hour exposure. Less radioactive minerals will take longer periods of time. (*right*) A prospector uses his Geiger counter to determine the radioactivity of a specific point in a generally radioactive area. A background count was taken before this specific reading was made. From *Prospecting for Uranium*, by U. S. Atomic Energy Com. and U. S. Geological Survey, 1951.

does in the scintillation counter. Small cylindrical instruments painted black on the inside, with an eyepiece containing a magnifying lens at one end and the screen at the other, can be used to detect radioactivity from high-grade specimens. The specimen is held near the screen in a dark room and, after the eye is adjusted to the darkness, the flashes can be seen through the eyepiece. *Scintilloscopes* are of no help in determining the amount of radioactivity.

Electroscope Test. The *electroscope* is a simple instrument used long before the atomic energy era for rough assaying of uranium ores. It is essentially a glass bottle with two narrow, thin, gold strips called *leaves* suspended from an insulated metal plug in the neck of the bottle. When an electric charge is applied to the leaves by rubbing a glass or plastic rod with a woolen cloth and touching the rod to the electroscope's metal plug, the leaves fly apart. Then, if a radioactive mineral is brought near the plug, the radiation will discharge the leaves and they will fall together again. The speed with which this happens is proportional to the amount of radioactivity.



PROSPECTING WITH THE COUNTER

This chapter deals with the application of the principles of radioactivity to its measurement in the field by means of the counter, and the interpretation of the results. The procedures for prospecting with a counter are the same whether one uses a Geiger counter or a scintillation counter, and the basic principles are the same for prospecting from the air or probing a drill hole as they are for prospecting on the surface.

FACTORS INFLUENCING COUNTER REACTION

Background Count. The first thing to understand about a counter is that there will always be some reaction when it is turned on even though it is not near radioactive minerals. There is radioactivity everywhere. All rocks contain minute amounts of uranium, and pulses are also produced by cosmic rays which strike the earth from outer space. Therefore, if a counter is operating, it will record the radioactivity from these sources known as the *background count*. It is the increase in radioactivity registered by the counter above the background count that is important.

To determine the background count on a counter with earphones or light, individual impulses must be counted for a period of a few minutes (the longer the period the more accurate the count), and divided by the number of minutes to arrive at the counts per minute. If the counter has a meter, the average location of the needle is noted over a period of time.

The background count will vary with different counters even of the same model. It will also change from time to time and place to place with the same counter and must be checked several times a day during prospecting. Background readings at one spot will vary due to variation in cosmic count and sensitivity of the counter; the latter is caused by weakening of the batteries, aging of the equipment, or changes in temperature. The background count will also vary considerably from place to place due to a change in the surface rocks, the topography, or the altitude. Light-colored igneous rocks, such as granite, are usually more radioactive than the dark-colored igneous rocks and most sedimentary rocks. Of the sedimentary rocks, black shale and phosphate-rich rocks are the most radioactive, and limestones are the least radio-

active; sandstones vary widely. Therefore, when the prospector passes from one type of rock to another, the background count may as much as double without there being any significance so far as a deposit of radioactive minerals is concerned.

Counter readings taken above soil are not as indicative as those taken above rock, but they will sometimes reveal highly radioactive rocks several feet below the surface. The radioactivity measured in such cases does not come directly from the rocks below, if they are more than a foot or so deep, but it originates with the decay products of the buried radioactive materials which have migrated to the surface in ground waters, by capillary action, or by other means. If the prospector is attempting a survey of soils, he must make certain that the soil he is working on was formed from the underlying rock and not moved to its present location by glacial action or by slumping from a cliff or steep slope. Under such conditions the soil would not represent the rocks below. Radioactivity measurements over soils or even over rock outcrops are also likely to be very unreliable in areas near extensive uranium mining, milling, or hauling operations. The radioactivity along many of the haulage roads in the Colorado Plateau area, for instance, is unusually high.

Cosmic Rays. Cosmic rays are radiation from outer space and account for part of average background radiation. Like the other components of the background count, cosmic activity is variable from time to time and place to place. It increases with elevation and in the higher latitudes and continually fluctuates at any one spot.

In a narrow valley or ravine the amount of cosmic radiation striking the counter will be less than on a level surface, since the ridges at either side will cut out some of the rays. These ridges will also provide surface radiation from the sides in addition to that from below, increasing the total surface radioactivity measured and further reducing the proportion of cosmic radioactivity in the background count. Under these conditions the counter reading may increase, decrease, or remain constant, depending upon the relative intensity of radiation from the ground and from cosmic rays at that particular place and time. Underground, most cosmic rays are eliminated by absorption, and nearly all radioactivity comes from the surrounding rock. Readings made underground for any rocks but those almost devoid of radioactivity will be considerably higher than those at the surface because the mass effect, described below, more than balances the decrease in cosmic activity.

Mass Effect. By far the most important fact for the prospector to understand and to keep continually in his mind about counter operation is the *mass effect*. The mass effect will come into play to some degree in nearly every measurement of radioactivity made, and in many cases the variation resulting from it is so great as to obscure completely the meaning of the measurement.

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The best way to avoid this difficulty is to see that the mass effect is as nearly as possible the same for each reading, or, if that cannot be done, to know how to compensate for it in the evaluation of the reading.

The principle of the mass effect relates directly to the fact that the counter does not measure the *proportion* or *per cent* of radioactive minerals or elements, or even radioactivity, in a given rock, but rather the *total amount* of radioactivity, whatever its source, that strikes and reacts in its tube or crystal. Part of this radioactivity is the background count made up of several sources, and the additional radiation is what must be measured. But this additional radiation is again *amount* or total quantity, not per cent, and the total quantity will vary with the size of the source as well as with the proportion and type of radioactive substance in the source. Thus, a large piece of rock gives off more radiation and results in a higher reading than a small piece of the same rock, and rock on three sides of a counter or all around it will give a much higher reading than the same rock on one side. Therefore, it is extremely important that, in comparing and interpreting counter readings, the relationship of the counter to the material tested, whether it be a sample or a rock outcrop, is as nearly as possible the same each time or that a correction factor is applied to the readings to take care of any variation. For example, a small specimen of moderately radioactive material might give a relatively low reading when held near the counter and away from the surface rock. But, if the counter probe is placed against the rock face from which the specimen came, a very much higher reading will be obtained due to the much larger source of radiation. However, the percentage content of radioactive material in the rock is the same. Finally, if the counter probe is placed in a crevice or hole in the rock face so that the rock completely surrounds it, or nearly so, a still higher count will be obtained.

The mass effect becomes more apparent as the radioactivity of rocks increases. Rocks of average radioactivity, such as most barren sandstone, provide little mass effect, and a lower reading may be obtained in a rock crevice, tunnel, or ravine because of the absorption of cosmic radiation.

If a prospector or miner does not understand and take into account mass effect, but operates under the impression that a counter that has been checked against a sample of known uranium or thorium content can be used to estimate directly the grade of an ore outcrop or dump, he is almost certain to make serious errors in judgment and either pass up a good deposit or waste his time exploring a deposit that is worthless.

Absorption. The effect of absorption of radiation presents the same problem in evaluating counter readings as does the background effect. Rock, soil, water, and air all absorb radiation, and the amount of radiation eliminated by absorption is proportional to the distance the radiation travels through one of

these media. For this reason, the count will vary depending upon the amount of air space between the counter and the material measured. The nearer the counter to the material measured, the higher the count. Consequently, just as in the case of mass effect, readings should be made under the same conditions—in this case, the same distance from the source of radiation—or a corrective factor must be applied in their evaluation.¹ In most cases the counter tube or crystal should be held not more than 24 inches from the rock surface in reconnaissance, and right on the surface in sample measurement or detailed prospecting.

Equilibrium Effect. Another important factor in using a counter is the problem of radioactive equilibrium, the principle of which was discussed in the preceding chapter. Since a counter cannot measure uranium or thorium directly, but measures the radiation of the daughter elements, it can give a reliable measure of the uranium or thorium content only when the material tested is in equilibrium. A chemical analysis, on the other hand, determines the actual content and is not influenced by the state of equilibrium. Therefore, when a counter assay differs from a chemical assay, the chemical assay is assumed to be correct. The difference between the two assays reveals the extent of inequilibrium.

There is no method for automatically correcting for lack of equilibrium in the field, but when working on a given deposit, the general degree of equilibrium of which has been determined by comparison of counter and chemical assays, rough adjustments can be made and readings translated into approximate percentages of uranium. For general reconnaissance and under other circumstances when it is not possible to test the equilibrium by getting chemical assays for comparison, it is important to recognize the conditions under which a counter reading may be reasonably reliable.

Most important uranium ore deposits in the United States and similar deposits elsewhere are in approximate equilibrium at least to a degree within the accuracy of field measurements which are affected by several other factors. Therefore, counter readings on the following types of deposits are generally reliable:

1. Carnotite deposits of the Colorado Plateau type.
2. Unweathered portions of pitchblende deposits.
3. Unweathered portions of copper-uranium deposits.
4. Deposits of uranium in asphaltic sandstone.
5. Deposits of uranium in limestone, such as those in the Grants district, New Mexico.

¹ This correction must also take into account the fact that, in addition to the absorption phenomenon, radiation intensity, like light, decreases in proportion to the square of the distance from the source due to distance alone.

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If there is evidence of weathering of the pitchblende or copper-uranium deposits, or recent movement of material by solutions in any kind of deposit, often evidenced by heavy staining of rock surfaces, a chemical assay should be obtained.

The following types of deposits are likely to be out of equilibrium:

1. Deposits of secondary uranium minerals in rock fractures, or disseminated deposits of secondary minerals, such as autunite, schroeckingerite, or torbernite.

2. Lacustrine deposits such as the schroeckingerite deposits at Wamsutter, Wyoming.

3. The weathered portions of any deposits containing sulfide minerals such as pyrite and chalcopyrite. The weathered portions of the copper-uranium deposits on the Colorado Plateau and the pitchblende veins at Marysvale, Utah, are out of equilibrium.

4. Radioactive coatings on mine workings.

5. The encrustations and rock coatings around radioactive springs.

Radon Effect. Misleading and confusing counter readings can be caused by concentrations of radon. Although radon cannot be directly detected with a field counter, it decays very rapidly into very radioactive daughter products that may adhere to dust particles in the air or collect on exposed surfaces. If the radioactive dust particles contaminate a prospector's clothing or his counter, erratic, abnormally high readings will result for several hours. This is most likely to happen in poorly ventilated mine workings. The effects of radon may also be encountered where radioactive rock is being broken by drilling and blasting underground.

Underground Effect. Underground, the mass, radon, equilibrium and cosmic effects and other special conditions make counter prospecting a very much more complex problem than on the surface:

1. Mass effect is extreme since the counter is completely surrounded by rock. Thus that proportion of the background count due to mass effect is very much increased.¹

2. Cosmic rays are greatly reduced, depending upon the depth below the surface. This decreases that part of the background count due to cosmic rays.¹

3. Radon may raise the background count to the point where reliable measurements are impossible.

4. In wet mines containing uranium minerals, tunnel walls may be coated with thin, but often spectacular, films of recently formed uranium salts. These

¹ Background readings in a mine are usually higher than those over similar rocks on the surface, but sometimes the reverse is true. If the rock has a low radioactivity the decrease in radioactivity due to absorption of cosmic rays underground may be larger than the increase in radioactivity due to the mass effect.

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are produced after mining by the action of ground water which dissolves the original uranium minerals elsewhere in the mine and deposits them by evaporation on the mine walls. Usually these coatings are fluorescent under ultraviolet light. Because they are only thin films, they are not of economic importance, although they may be indicative of nearby ore bodies. The fact that they are recently formed and have not had time to reach equilibrium means they will give relatively low readings in spite of their rich appearance.

5. Counters that are not moisture-sealed may quickly become useless in a wet mine.

Thorium. Since thorium, like uranium, is the parent of a series of radioactive elements, it too will activate a counter, and it is impossible to tell by means of most field counters presently manufactured whether uranium or thorium or both supply the radioactivity measured. This is just one more of the many good reasons why a prospector, to be successful, must use the counter intelligently and merely as a tool in conjunction with a very good knowledge of the occurrence of the uranium and thorium minerals. It is usually possible, with a good knowledge of the subject, to tell by the general type of rock formations in which one is working and by identification of the minerals present, whether one is dealing primarily with uranium or with thorium. Since uranium and thorium often occur together, however, the effect of thorium radiation in counter readings on uranium deposits and the effect of uranium on the count obtained from a thorium deposit must always be considered. Fortunately, thorium is not often a vital factor in the important types of uranium deposits. However, in pegmatites, granite, and some vein deposits, radioactivity believed to result from a few obvious uranium minerals may be largely due to more common but less easily noticed thorium minerals.

The radiation from the thorium series is about one-third that of the uranium series, so that a sample containing a given amount of uranium will give a count of about three times that of a sample of the same size and containing a similar amount of thorium. Thus, radiation from small amounts of uranium becomes a much more important consideration in counter readings on thorium deposits than the thorium effect on uranium deposits. Depending upon the prospector's evaluation of the mineralogy of a thorium deposit, he should reduce his estimate of thorium content based on counter readings 10 per cent or more to allow for the uranium present.

THE PORTABLE FIELD COUNTER

Buying a portable field Geiger counter can be very easy, or very difficult, depending upon the discrimination of the buyer, because of the large number of makes, models, styles, sizes, and prices. The less expensive ones may be purchased for as little as \$30 at Sears Roebuck, from mineral dealers, or at

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many hardware or camp-outfitting stores, or in the western states even at drug stores. The more expensive ones must be obtained from the manufacturer or his distributor and range in cost up to \$300 or more. Portable scintillation counters are much more limited in availability and begin in price at the \$300 figure, ranging upward to about \$1,000 or more. A list of manufacturers and major distributors of both types is included in Appendix VIII.

The experienced prospector will have specific ideas as to the exact type of instrument that best suits his needs. The beginner, on the other hand, is advised to start out with one of the inexpensive models. Experience in using a counter and an understanding of its principles of operation and limitations are much more important than the type of counter and the special features it may have. Instructions for the operation and care of any particular model can be obtained from the manufacturer and should be carefully studied and followed.

There are four principal methods for using the counter in prospecting, all or any combination of which will be used by the prospector. These are general reconnaissance, outcrop testing, radiometric surveying, and sample testing.

General Reconnaissance. General reconnaissance with the counter is the simplest method of counter prospecting and consists of nothing more than walking over the area selected for prospecting with the counter turned on and held at a constant distance from the ground. The counter may be kept in its carrying case or held in the hand. If it has an external probe, it may be strapped to a walking stick, to the leg, or merely slipped into the top of one's boot to bring it closer to the ground. While walking, the prospector must either wear the earphones and listen for increases in the counting rate or keep his eye on the blinker or ratemeter.

After having arrived in the area of interest, but before starting the reconnaissance, the background count must be checked, and this should be repeated every hour or so. In reconnaissance of this type the counter will register only the background count most of the time and the prospector will quickly recognize any substantial change due to encountering radioactive material. It is important, however, not to confuse such changes in counting rate with changes due to different rock types, topography, or fluctuation in cosmic activity.

If at any place the counter registers an appreciable increase in counting rate, the prospector should stop and measure the rate, comparing it to the background count. If the rate is two or three times the background, a close examination should be made by moving the counter (or the probe) slowly over the rock or ground surface in order to determine exactly the source of the radioactivity. At this point, the importance of knowing the uranium and thorium minerals and something of their occurrence becomes evident, because the prospector must try to identify what is causing the radioactivity. For example, he should try to determine whether the radioactivity is coming

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from a small vein or pocket of high-grade uranium or thorium minerals that might be an important find, or from a larger area containing sparsely distributed minerals of low radioactive content which, because of the mass effect, has caused the higher reading, but which may be of no importance as a source of uranium or thorium. A large area of weakly radioactive rocks may cause the same effect on the counter as a small specimen or vein of high-grade ore.

If an area is encountered that consistently gives readings of several times background, it should be carefully prospected. The high readings may either represent a large, relatively low-grade deposit, or indicate the presence of a higher-grade deposit somewhere in the vicinity.¹ If the radioactivity at any particular place is four or more times background, a sample should be taken.

In reconnaissance with the counter, it is important not to walk too rapidly, for then the counter may not have time to register narrow streaks or small spots of radioactive minerals. The few additional clicks in the earphones or flashes of the light from a rapidly passed source of radioactivity are likely to be confused with a "burst" of cosmic radiation or other normal fluctuations, and a ratemeter may show no reaction at all.²

In areas where preliminary reconnaissance indicates repeated readings appreciably higher than background, it is good practice to stop frequently and take readings of one minute or more³ with the counter or probe on the ground.

¹ In some cases, only a slight increase in background count, if it is consistent over an area and cannot be related to a change in rock type, may indicate favorability for further prospecting.

² This is because of factors called *statistical error* and *time-constant*.

Statistical error: All counter readings fluctuate due to the fact that gamma rays trigger the counter at irregular intervals of time. This is particularly a factor with a counter having headphones or a neon light to detect individual pulses which occur in bunches or clusters. It is for this reason that counts taken over longer periods of time are more accurate.

Time-constant: All counters having meters use integrating circuits to receive and smooth out the irregularly spaced, individual impulses from the amplifier and to provide an average reading. If the circuit is adjusted to average counts over a relatively long period of time, the instrument is said to have a long time-constant. With a long time-constant, fluctuations of the meter needle are slight, and the meter reading is stable, but the meter has a sluggish response to changes in radiation. With a short time-constant, the needle fluctuates widely, and an average reading may be hard to obtain. If the time-constant of a particular instrument proves unsatisfactory, it can be modified by a radio serviceman. Some of the more expensive counters have several time-constants which can be selected by a switch.

³ When counting individual pulses, the larger the number of pulses measured, the greater the accuracy. Thus, accuracy is improved by increasing the length of the counting period or by using an instrument of higher sensitivity that will react to a larger proportion of the radiation; accuracy is automatically improved as the degree of radioactivity being measured increases. The need for accuracy depends upon the purpose of the reading. For a quick check on an outcrop, counting for a few seconds with the average counter is adequate. Background readings should be taken over a period of at least a minute. Readings for detailed outcrop testing, sample analysis, or radiometric surveying should be not less than 3 minutes.

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Outcrop Testing. If a radioactive vein or bed is discovered during the general reconnaissance, a good preliminary estimate of its importance can often be made by systematic counter measurements along its outcrop. Three-minute readings should be taken at regular intervals, about every 5 feet, along the vein or exposed edge of the bed with the probe or tube lying across the outcrop perpendicular to the long dimension and placed in the center of the outcrop if it is wider than the length of the probe.¹ These readings, less the background count, and their location should be recorded. At the location of about every tenth reading, a sample should be taken for chemical assay. When the results of these assays are available, they can be used to calculate the uranium or thorium content at the locations where samples were not taken, permitting a reasonably good preliminary estimate of the grade of the entire length of the outcrop with a minimum of sampling and assaying. Care must be taken at each reading that the probe is always in the same position relative to the outcrop to minimize the error from mass effect, absorption, and other factors. Many more experienced prospectors, after having become thoroughly familiar with their counters and various methods of field prospecting, can make rough estimates of the grade of an outcrop without collecting samples or prior to receiving the assays. This, of course, involves the assumption that the material being measured is in equilibrium or in approximately the same degree of equilibrium as material previously tested. If this is not true, serious errors can be made. This method should never be used for a final appraisal of a deposit.

Radiometric Surveys. If a general reconnaissance indicates an area of unusually radioactive rocks, it may be desirable to make a systematic radiometric survey, sometimes called a *grid survey*, to determine the pattern of the radioactivity and to see whether it may reveal information that could be of value in finding and developing a commercial ore body. Such information on the distribution of the radioactivity can be very useful in planning outcrop sampling, test pitting, diamond drilling, or underground workings. In this type of survey the area under investigation is marked off with a compass and tape or by pacing in a grid pattern with squares 10, 20, or more feet on a side, depending upon the size of the area and the observed degree of variation

With a ratemeter this problem is automatically handled by the time-constant of the integrating circuit, and it is necessary only to wait a few seconds until the needle becomes reasonably steady before taking the reading. The longer the time-constant, the longer this will take. Although the long time-constant gives greater accuracy, the resultant sluggishness of the needle is often undesirable for reconnaissance work. The proper time-constant will vary with the use to which a counter is put.

¹ If a scintillation counter is used with the crystal at the end of the probe, it should be held vertically and in the center of the outcrop.

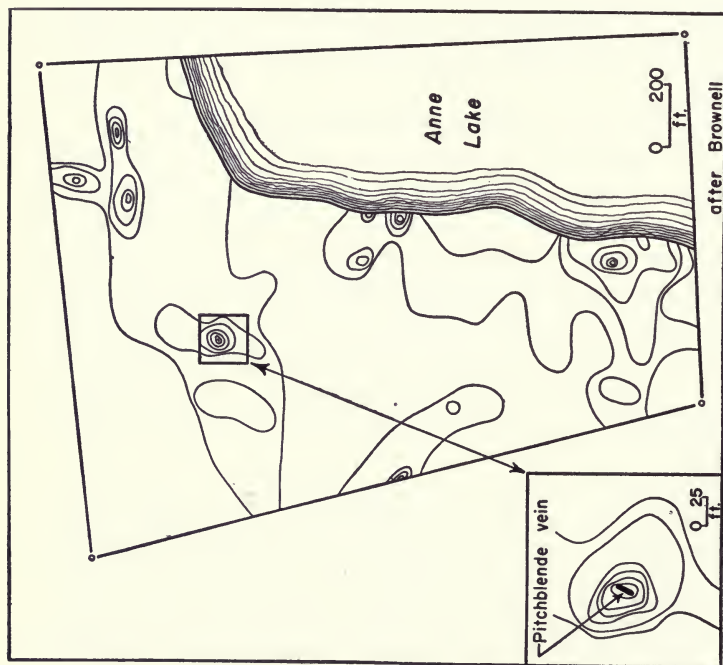


PLATE XXVII. Radiation survey of the Jim Claim, Saskatchewan. The radiation survey of this claim showed a previously unknown radioactivity high in the northern portion of the area. Exploration here resulted in the discovery of a pitchblende vein. From *Prospecting With a Counter*, R. J. Wright. Courtesy U. S. Atomic Energy Commission.

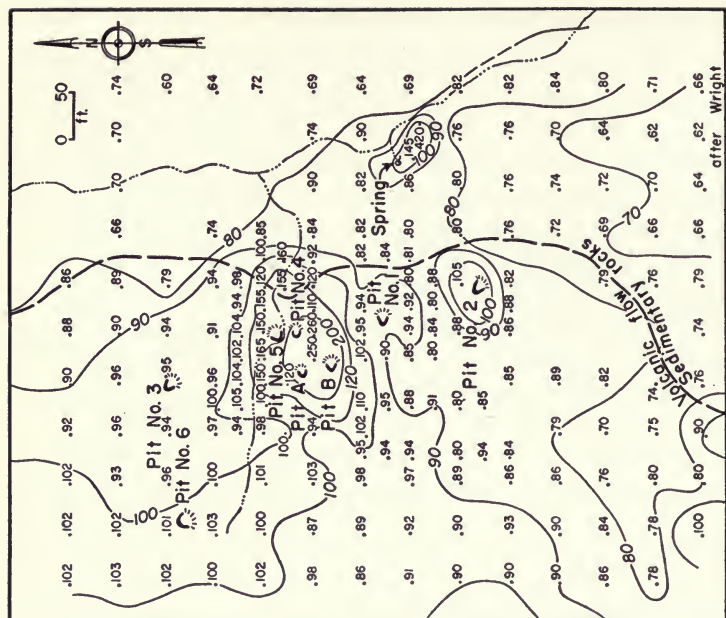


PLATE XXVIB. Radiation survey of the Annie Laurie prospect, Arizona. This survey was used to locate the test pits. Note the difference in background radioactivity between the sedimentary rocks and the volcanic flow. Radioactivity was first discovered here when the spring deposits were tested with a counter. From *Prospecting With a Counter*, R. J. Wright. Courtesy U. S. Atomic Energy Commission.

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in radioactivity from place to place.¹ Readings are taken with the probe on the ground over a counting period of at least one minute at stations located at the corners of the squares. If a ratemeter is used, the needle fluctuations can be averaged by eye; otherwise the number of individual counts is recorded.

After a count has been made at each station, the stations and corresponding readings are plotted on a map. The readings can be recorded on the map in one of the following ways:

1. The actual counter reading in counts per minute or mR/hour.²
2. The net counter reading in counts per minute or mR/hour after subtracting the background count.
3. The ratio of counter reading to background. That is, the reading is expressed in terms of the number of times it is greater than the background count. A reading of 125 counts per minute in an area where the background is 50 would be expressed as 125/50 or 2.5.

The second and third methods are preferable because they eliminate the background count. The background is obtained by taking the average of several readings immediately outside the area being surveyed.

When readings have been plotted on the map, lines are drawn connecting the points of greatest radioactivity represented by the highest figures. Then lines are drawn connecting the points of next highest radioactivity and so on until a *contour* map showing lines of equal radioactivity or *isorads* has been prepared in the same manner that a topographic map shows lines of equal elevation. Such a map, showing the location, size, and shape of the areas of highest radioactivity may provide a clue to an ore zone or mineralized structure that is not apparent to the eye or by simple counter reconnaissance.

¹ Wide variation in radioactivity over short distances will require a closer spacing of readings to determine accurately the pattern of radioactivity and thus a smaller grid.

² The unit of measurement used on most ratemeters is the same as that used to measure X-rays. This standard unit is the *roentgen* (R) which is a measure of the quantity or amount of radiation, regardless of whether that quantity is produced quickly by intense radiation or slowly by slight radiation. Therefore, the intensity of radiation is expressed as a rate or as roentgens per unit of time. Since radioactivity in nature is low compared to X-rays or other artificial sources of radiation, most counters are calibrated in *milliroentgens*, 1/1000 roentgen (mR), per hour.

Average background radioactivity on the earth's surface is in the range of 0.02 to 0.05 mR/hr which is measured on the most sensitive (01) scale of the three scales usually found on a ratemeter. These are usually referred to as the "01," "1," and "10" scales because they measure hundredths of milliroentgens, milliroentgens and 10's of milliroentgens, respectively. If a source of radiation is so strong that the needle starts to go off the scale, the sensitivity can be changed to the next highest (less sensitive) scale by turning a control knob. Some scintillation counters and a few Geiger counters have meters which read directly in counts per minute or counts per second. A very few counters have their meters calibrated in terms of per cent uranium or U₃O₈. Since there are a large number of reasons why it is impossible to measure the uranium content directly, this type of scale is not valid and should be used in the same manner as those calibrated in milliroentgens.

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To make certain that as much useful information as possible is available on the map, the counter should be left on while moving from one station to the other and additional readings taken and plotted between the stations at any point where a marked change in radioactivity is noted. The scintillation counter is particularly well adapted to radiation surveys because of its high counting rate (sensitivity) and long time-constant, permitting very reliable readings, and the added advantage with some instruments of being able to check the sensitivity to make certain it does not change during the survey and to adjust it if changes do occur.

Radiometric Assaying. The only completely reliable way to determine the exact uranium or thorium content of a sample is to obtain a chemical analysis which determines either or both of them directly and is not affected by the proportions of each or its daughter products present. Analyses are expressed in terms of uranium oxide, U_3O_8 , or thorium oxide, ThO_2 . To indicate that an assay was made by chemical methods, the symbols "chem." or "c" are usually used after U_3O_8 or ThO_2 . For example, 15% U_3O_{8c} . If a sample is in equilibrium, a reasonably accurate analysis of either uranium or thorium can be made by measuring its radioactivity if there is not a significant amount of the other present. This fact must be determined in advance by other means—by a knowledge of the minerals in the sample or by chemical analysis of other samples from the same deposit. Such measurements can be made quite accurately, given the conditions described, with laboratory counters especially designed for the purpose and now used in most government and large commercial laboratories. Their advantages are the speed with which the assays can be made and the low cost.

The sample is crushed, ground, and placed in a sample holder surrounded by a lead shield which very much reduces the background count. The instrument records the number of counts during a given counting period, or the length of time taken to record a given number of counts. The radiometric assay can then be determined from the recorded count or time interval by the use of a graph which has been prepared for that specific counter on the basis of measurements taken on chemically assayed "standard" samples. The assay is expressed as " U_3O_8 (or ThO_2) equivalent." An assay of 0.26 per cent U_3O_8 equivalent means that the sample has the same degree of radioactivity as a sample which is in equilibrium and contains 0.26 per cent U_3O_8 by chemical analysis and that has no thorium present. The symbols U_3O_8 equiv., U_3O_{8e} , or U_3O_8 rad. (or ThO_2 equiv., ThO_{2e} , or ThO_2 rad.) are usually used for radiometric assays.

Portable field counters can be used to make rough assays of samples by using the same general procedure for laboratory radiometric assaying described above.

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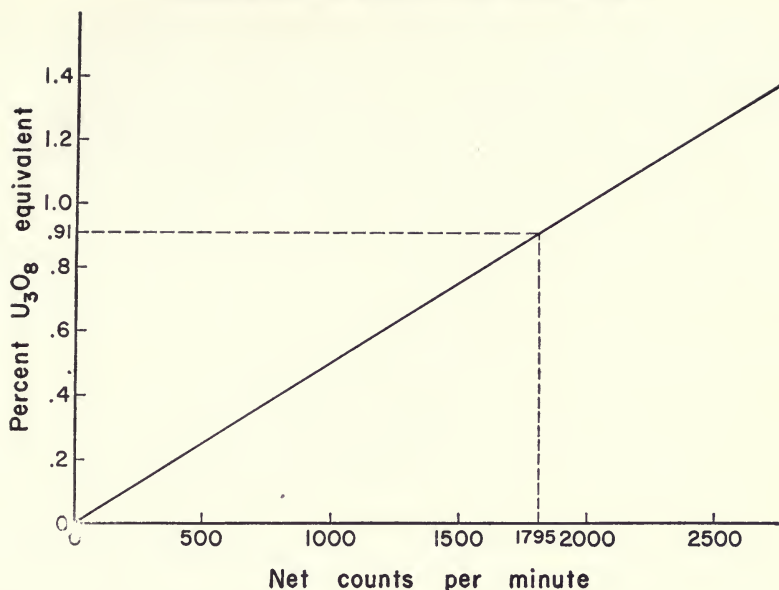


PLATE XXVIIA. Calibration chart for a laboratory counter. By use of the graph the radioactivity of a rock sample can be recalculated as percent U_3O_8 equivalent; for example, a sample which yields 1795 net counts per minute assays 0.91 percent U_3O_8 equivalent. A calibration chart can be used only for the counter for which it was prepared. From *Prospecting With a Counter*, R. J. Wright. Courtesy U. S. Atomic Energy Commission.

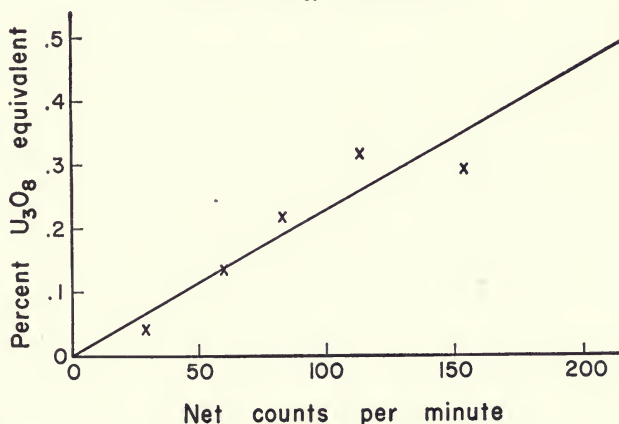


PLATE XXVIIIB. Calibration chart for a field counter. This graph was prepared by plotting the radioactivity of five assayed samples, indicated by x. A field counter is less sensitive than a laboratory counter and hence detects fewer counts for a given amount of uranium. From *Prospecting With a Counter*, R. J. Wright. Courtesy U. S. Atomic Energy Commission.

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This method of assaying has been called the *counter comparison test* and involves the following steps:

1. Record the background count.
2. Place next to the center of the counter probe a standard sample having a uranium or thorium content of the same general range that it is believed the unknown sample may have, and record the count.
3. Remove the standard sample, take the background count again, and place the unknown sample in the same position relative to the probe as the known sample was placed, and record the count. The unknown sample should be the same size as the standard sample, and preferably both samples should be crushed or ground and in containers of the same size.
4. Subtract the background count from the sample count in each case. Then, the uranium or thorium content of the unknown sample is to the content of the known sample as the net count of the unknown sample is to that of the known. For example:

Unknown = 200 cpm above background; known = 100 cpm above background

$$\frac{\text{Unknown}}{\text{Known}} = \frac{200}{100}; 100 \times \text{unknown} = 200 \times \text{known}$$

$$\text{Unknown} = \frac{200}{100} \times \text{known} = 2 \times \text{known}$$

If known = 0.5% U_3O_8 ; unknown = 1.0% U_3O_8

For this test, counts of at least three minutes' duration should be made, and a direct count rather than a meter reading is preferable for greater accuracy. If the probe has a window to permit recording of beta radiation, it should be used.

Counter Care and Maintenance. All of the electronic components of the Geiger counter are standard items and can be repaired or adjusted by a qualified radio serviceman. The Geiger tube, however, must usually be replaced if it ceases to function properly. Many radio shops in the western states now make a regular business of checking and repairing counters. If operating difficulties are encountered with the counter, the first thing that should be checked is the tube simply by replacing it with another to see if the difficulty is eliminated. The prospector should, if possible, always carry a spare tube.

Scintillation counters are somewhat more complicated than Geiger counters and may require extensive work by an expert if they break down. In the scintillation counter there are two parts that cannot be repaired and must be replaced when they fail—the crystal or phosphor and the photomultiplier tube.

PROSPECTING WITH THE COUNTER

Most portable field counters are built to stand considerable rough handling, including the usual number of knocks and bumps. However, they are basically delicate instruments, and the more protection they are given against abuse, the longer and better they will operate. The following rules will help:

1. Protect the counter from direct contact with water. Do not use it in the rain, and protect it with a waterproof case or covering when in wet mines.
2. Do not use it in excessively humid climates or regularly in wet mines unless it has been "tropicalized." Tropicalized counters can be purchased for an additional cost.
3. Do not allow it to become overheated.
4. Do not allow it to come in contact with ore samples, radioactive dust, or radon-saturated mine air.
5. Do not allow the counting mechanism to operate so rapidly that the individual clicks cannot be distinguished or the meter hand swings off the dial. To avoid this, adjust it to a less sensitive scale or move it farther away from the source of radioactivity.

When a counter ceases to operate for no apparent reason it is often because the batteries need replacement. Depending upon the complexity of the counter, it may operate on simple flashlight batteries or on several different types of batteries. The manufacturer's instructions provided with the counter show how the batteries should be replaced. Care should be taken to follow these instructions to the letter in order to avoid shock from the high-voltage power supply which may be as high as 1,000 volts in some counters.

THE AIRBORNE COUNTER

Another type of counter that is rapidly gaining popularity among prospectors who own aircraft or can afford to rent a plane periodically is the *airborne counter*. Actually it is hardly a different instrument, but merely a more elaborate version of the Geiger or scintillation counter adapted for aerial use.

The earliest such instruments were Geiger counters with banks of a dozen or more tubes of up to 40 inches in length. These could attain the necessary increased sensitivity to record the reduced radiation that results from passage through several hundred feet of air. In fact, for rough aerial reconnaissance work, portable Geiger counters, altered so that a larger tube could be interchanged with the regular one, have been used successfully.

With the development of the scintillation counter, however, it became readily apparent that it was the answer to the increased sensitivity problem and very few Geiger counters are any longer in use for aerial work. Scintillation counters especially built for aerial use with larger crystals and automatic recording mechanisms are manufactured for from \$2,000 to \$5,000. Many prospectors,

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PLATE XXVIII A. Piper Cub equipped for low-level or rim flying. *Courtesy Engineer ing & Mining Journal.*



PLATE XXVIII B. DC-3 equipped for high level grid flying (Rum Jungle area). *Courtesy Australian News & Information Bureau.*

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however, have used successfully one of the better portable instruments in small aircraft that can cruise at 60 to 90 miles per hour from 50 to 100 feet from the ground.

Reconnaissance. The methods of prospecting and surveying with the portable field counter have their equivalents in the aerial use of the counter. The simplest method is reconnaissance—flying at random over areas believed favorable for radioactive materials with the counter continuously operating. If an unusually high reading is encountered, the plane circles and crisscrosses the spot to attempt to locate it as exactly as possible on a map or aerial photograph so that it may be investigated on the ground. For this type of flying, a slow-flying, small plane with high climb efficiency is required. The plane is flown as close to the ground as is possible with reasonable safety, 50 to 150 feet, and an attempt is made to stay at a constant elevation above the ground. The same factors involved in evaluating counter readings in surface work must be considered in aerial prospecting. For example, a large area of granite, which has a little more than the usual content of radioactive minerals, will often cause a reading from the air that is very similar to that resulting from a narrow vein of high-grade pitchblende.

Rim Flying. Rim flying is really a form of reconnaissance, but with the specific purpose of following the outcrop of a favorable rock layer along steep canyon walls and the edges of mesas. This is a very common method in the Colorado Plateau region. In this type of flying, the rock being surveyed is to one side of the plane rather than below, and an attempt is made to keep within about 50 feet of the cliff face.

Grid Flying. Grid flying is the equivalent of the radiation or grid survey with the portable field counter, and it uses the same principle and produces the same results—a map showing contours of equal radioactivity or *isorads*. Grid flying is more complicated than the grid survey on the ground, however, because of the problem of recording the exact location of the plane with respect to the ground at all times. And, of course, the readings are taken continuously rather than at stations. A good job of grid flying requires a trained crew and would not be worthwhile for the average prospector to attempt. Both the Atomic Energy Commission and the Geological Survey do this type of work. The Survey uses a DC-3 plane flying at about 600 feet elevation, and the Commission uses light planes for more detailed work at lower speeds and elevations. Several private firms are also equipped to do aerial scintillation counter surveys.¹ When such surveys are made in conjunction with aerial magnetometer surveys, which are frequently done for mining and petroleum companies, the additional cost for the scintillation survey is relatively small.

¹ See Appendix VIII.

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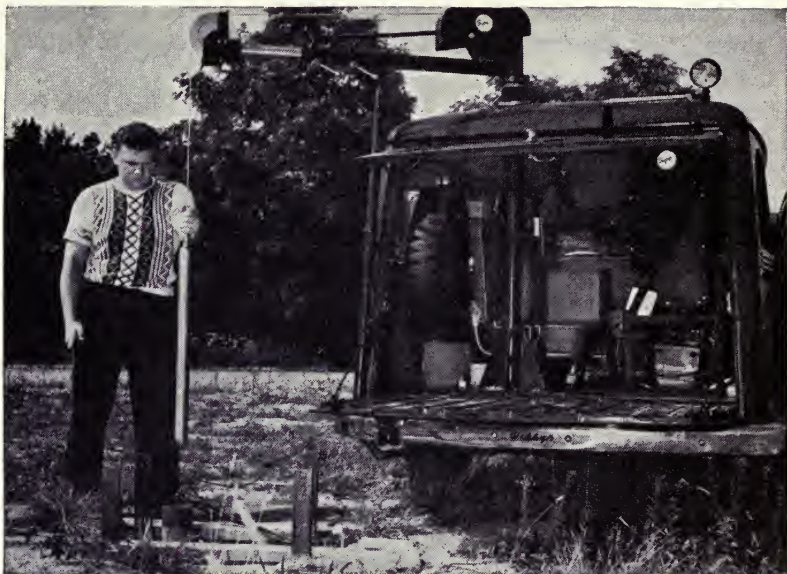


PLATE XXIXA. Mobile Drill Hole Scintillation Counter. *Courtesy Health and Safety Lab., New York Operations Office, U.S.A.E.C. Photograph Brookhaven National Lab.*

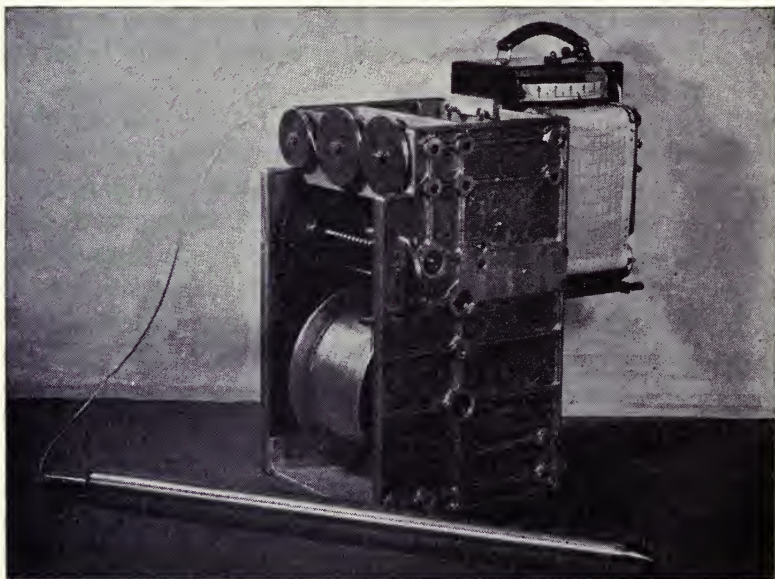


PLATE XXIXB. Portable Drill Hole Scintillation Counter. *Courtesy Health and Safety Lab., New York Operations Office, U.S.A.E.C.*

PROSPECTING WITH THE COUNTER

DRILL HOLE COUNTER

Like the airborne counter, the *drill hole counter* is merely an adaptation of either the Geiger or scintillation counter to permit lowering the probe into a drill hole and recording the changes in radioactivity as it moves down or up the hole. Also like the airborne counter, the earlier instruments were Geiger counters, but they are now being rapidly replaced with the scintillation counters because the greater sensitivity permits much more rapid movement of the probe in the hole and detection of much smaller changes in radioactivity. Techniques of hole logging are rapidly being developed to the point where they are gradually reducing the amount of core drilling required in uranium exploration. In addition to detecting ore, a sensitive drill hole counter can be used under certain circumstances to distinguish between different rock formations penetrated by a drill hole on the basis of differences in radioactivity, thus providing much of the geological information which could otherwise be obtained only from a drill core and which is necessary to carry out intelligently a drilling program.

Although less elaborate, portable instruments suitable for probing drill holes can be obtained for as little as \$350, the instruments in use in large exploratory operations, usually mounted on trucks or jeeps and with the most modern type of operating and recording devices, cost in excess of \$1,000.

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XXI

HOW TO EVALUATE A DISCOVERY

The author's purpose in preceding chapters was to equip the prospector with a basic understanding of the occurrence of uranium, thorium, and beryllium, and to provide him with a working knowledge of the tools available with which to search for them. The important question now is: How can he make a reliable evaluation of any discovery he might make? There are many good books that discuss at length the various methods of prospecting and mining property examination and evaluation that are applicable to all minerals. However, a few observations will be made.

GEOLOGIC FEATURES

The most important thing to look for first, and to understand, in the evaluation of a discovery, is the geology—the geologic features of the mineral occurrence. Comparison of the geologic features of a new discovery with those of known deposits throughout the world provides the best clue to the importance of the find. For example, if one discovers a pegmatite while searching for uranium, he should know immediately that his discovery has little chance of becoming an important uranium producer. On the other hand, if one is prospecting for beryllium, the pegmatite is just what is wanted. One then proceeds to determine whether or not it actually contains beryl and, if so, what the size, grade, and potential tonnage of the deposit are.

The prospector must also keep in mind the type of occurrence and associated geologic features most likely to exist in a given area under examination. In the Colorado Plateau region, for example, he is most likely to find the flat-lying type of uranium deposit, the carnotite, copper-uranium or other similarly occurring deposits. He should look for the characteristic yellow or yellow, blue, and green stains on the canyon walls, for the thick sandstone or conglomerate lenses, and for the bleached, gray shale zones—the outstanding features of these deposits. On the other hand, if he is in the Colorado Front Range he should look for narrow veins in granite, gneiss, or schist with the obvious quartz and sulfide vein fillings and black pitchblende pockets.

The recognition of the structural features of a mineral deposit is very important in evaluating the extent of a discovery. There are many complicated

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geologic structures, most of which have been named by geologists and miners. While it is not necessary to be familiar with all of the terms, the prospector should understand and be able to describe clearly to someone else what he sees in a deposit. A few basic definitions will help point up the major structural features that should be noted.

Strike: The direction of a vein or bed along an actual, or assumed, level surface. If the surface is irregular, imagine planing it off. What direction would the outcrop take along the imaginary horizontal surface? Express as a bearing, that is, north, northeast, etc.

Dip: The slope or inclination of the vein or bed measured from the horizontal in a direction perpendicular to the strike. The degree and direction of inclination are expressed: 30° north; 50° southwest; etc.

Ore-shoot: That part of a vein that is ore—an ore zone in a vein.

Pitch (of an ore-shoot). The slope or inclination of the ore-shoot within the plane of the vein, or the angle between the axis of the ore-shoot and the strike of the vein, expressed in the same manner as the dip.

Plunge or rake (of an ore-shoot). The inclination of an ore-shoot measured from the horizontal in a vertical plane rather than in the plane of the vein and expressed in degrees and direction.

In measuring the dimensions of a vein or ore-shoot, the length is measured along the strike (*strike length*). At any given level in a mine, the horizontal length is called the *stope length*. The distance between the two extreme ends of an ore-shoot is the *pitch length*. The *breadth* of an ore-shoot is measured perpendicular to the pitch in the plane of the vein; the *width* is the thickness measured perpendicular to the plane of the vein. *Depth* may be measured along the dip or pitch or vertically, but one must specify which is used.

SAMPLING

The next important data in the evaluation of a discovery are obtained by adequate and careful sampling. The analysis of representative samples, properly related to the geologic structure of a deposit, is the only reliable way to appraise it. In sampling, the word *representative* should be held firmly in mind. What is wanted is a collection of samples that will accurately measure the grade of the entire ore body or of that part of it that is exposed and accessible. This means, first, that the individual sample taken at a particular spot must have the true proportions of all the components of the ore body itself at that place, and, second, that sufficient samples must be taken at regular intervals along the vein or bed to make sure that variations in grade are properly reflected in the samples. The following suggestions will help insure adequate sampling:

1. Clean away all soil and loose rock from the surface to be sampled. A whisk broom will be found useful.

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2. Dig a small trench 2 or 3 inches wide and an inch deep across the outcropping of the ore. This is called *channel* sampling.

3. Do not take more soft material than hard and do not discard obvious waste material included within the sample width.¹

4. Repeat this procedure at intervals of from 5 to 20 feet, depending upon how uniform the deposit looks.

5. Number each sample and note the sample width and location.

In some types of deposits, such as placers or irregularly distributed mineralization in fracture or shear zones, a different sampling method must be used. Sampling of placer deposits is usually done by digging a series of pits on a grid pattern so that individual pits are separated by distances of 10 to 100 feet, depending upon the variation expected in the deposit. This same method can be used for a flat-lying bedded or broadly disseminated deposit near the surface. When the deposit is at, or very near, the surface, this method can be combined with the radiation survey technique, and samples need be taken only at a few of the stations for calibration of the counter. Counter readings then replace samples for the intervening stations. Counter readings may be taken with the probe in the pit, but conditions must be the same at each station.

In sampling placer deposits, either the material as it comes from the pit is used as the sample, or the heavy minerals, concentrated by panning, are used. An accurate record must be made of the weight of the sample, and in the latter case, the weight of the original gravel from which the concentrate was derived as well.

Sampling of irregular, nonbedded deposits should be patterned as nearly as possible after the method for placers or near-surface bedded deposits. A number of several-pound samples should be taken by breaking or digging them from locations as evenly distributed over the deposit as is feasible. This method is also best for sampling ore dumps, although the *grab sampling* method of taking a piece at random here and there over the dump will sometimes be sufficient for a preliminary appraisal.

If the deposit being sampled is of considerable thickness, individual samples taken by the methods suggested may be quite large and may require reduction in size before being sent for assay. This is done by crushing the sample to particles of half-inch size or smaller with a sledge hammer and mortar and pestle, taking care not to lose any of the sample or to contaminate it, and then *cone and quartering* or *splitting* it by a mechanical splitter, of which there are several types. In cone and quartering, the crushed sample is well mixed on a clean surface, made into a cone and flattened with a shovel, and divided into quarters. Opposite quarters are discarded and the procedure repeated until the desired

¹ Sample width, in mining, means the width or thickness of material sampled and is really the length of the channel cut to take the sample.

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sample size is obtained. For most purposes, final samples should be no smaller than one pound and not larger than ten pounds. The larger the original sample the more representative it will be, but that advantage can be lost if the reduction in size is not done properly.

When sampling deposits in which the type of mineralization and the manner of occurrence are obscure, it is well to take a few choice specimens from what appears to be the richest part of the deposit for mineralogical study by a qualified laboratory to obtain additional information that may be of aid in evaluating the deposit.

The sampling of beryl deposits in pegmatites presents a special problem. One is then dealing with an irregular distribution of individual beryl crystals in the pegmatite. The two methods normally used are (1) obtaining large bulk samples of several hundred or several thousand pounds from the beryl zone of the pegmatite, and (2) counting the beryl crystals in a given area of exposed rock surface and estimating the beryl content on the basis of the number of crystals per unit area and their estimated average size.

ORE RESERVE CALCULATIONS

The end purpose, of course, of all prospecting, outcrop evaluation, and sampling, is to find an ore body. Since, by definition, an ore is something that can be mined and sold at a profit, it is desirable to determine as soon as possible the approximate gross value of the ore in order to know whether it is sufficient to cover the cost of mining and leave a margin of profit. No attempt will be made here to discuss the problem of estimating mining costs. If the prospector has had no experience in that field and wishes to mine a deposit himself, he should immediately obtain the services of a qualified person. The same holds true for accurate ore reserve calculations. The average prospector can, however, make helpful preliminary estimates of ore reserves and grade after a reasonable amount of sampling, by measuring the dimensions of the deposit or that part of it that is exposed.

1. Multiply the true width or thickness by the strike length times the inclined depth or pitch length, actual or estimated, to obtain the volume in cubic feet,¹ making sure that the dimensions are limited to that portion of the deposit which sampling shows to have a marketable metal content.

2. Estimate total tonnage by dividing total cubic feet by the number of cubic feet of the particular material being sampled required to make one ton. The number of cubic feet to the ton will normally vary from 10 to 15 depending

¹ For ore bodies pitching at angles of 30-35 degrees or more, the volume can be estimated by substituting the width in the horizontal plane for the true width and the vertical depth for the inclined depth.

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upon the specific gravity of the ore.¹ The figure for typical carnotite ore is about 13 cubic feet to the ton. The figure for a high-grade pitchblende lode, on the other hand, might be only about 6 cubic feet to the ton.

The value of the ore per ton is figured on the basis of the assays and the current price of the marketable constituents. Uranium, vanadium, copper, and many of the base metals are bought by the pound of metal, or oxide of the metal, in the ore. The value per ton is figured as follows:

$$\frac{\text{assay (per cent)} \times 2000 \text{ (pounds per ton)} \times \text{price (per pound)}}{100}$$

Gold and silver are paid for by the troy ounce, but assays are reported in troy ounces per ton so that the assay multiplied by the price equals value per ton.

Beryl is paid for by the *unit*, defined as 1 per cent beryllium oxide (BeO)

¹ The specific gravity may be determined by one of the following three methods:

1. Weigh a representative piece of the ore on an ordinary spring scale, then lower it into a bucket of water and take the weight again. The specific gravity equals the weight in air divided by the loss of weight in water:

$$\text{Sp. Gr.} = \frac{\text{weight in air}}{\text{weight in air} - \text{weight in water}}$$

2. Identify the minerals in the ore and estimate their relative proportions, then look up the specific gravity of each mineral and calculate the average specific gravity of the ore. The ore must be compact with no apparent open spaces for this method to be used successfully. For example: quartz = 50%; pyrite = 30%; pitchblende = 20%.

| | |
|-------------|-------------------|
| quartz | 50 × 2.65 = 132.5 |
| pyrite | 30 × 5.00 = 150.0 |
| pitchblende | 20 × 7.50 = 150.0 |
| 100 | 432.5 |

$$\text{Sp. Gr. of ore} = \frac{432.5}{100} = 4.32$$

3. If the ore is soft or loosely packed it is possible to excavate a measured volume of the ore, weigh it, and compare the weight per cubic foot with the weight of a cubic foot of water or 62.4 pounds. The volume must be determined by measuring the excavation and not the material after removal:

$$\text{Volume of excavation} = 1' \times 1\frac{1}{2}' \times 2' = 3 \text{ cubic ft}$$

$$\text{Weight of material removed} = 600 \text{ pounds}$$

$$\text{Pounds per cubic foot} = \frac{600}{3} = 200$$

$$\text{Specific gravity} = \frac{200}{62.4} = 3.2$$

When the specific gravity is known, the cubic feet per ton is calculated as follows:

$$\text{Sp. Gr.} \times 62.4 = \text{pounds per cubic foot}; \frac{2000}{\text{pounds per cubic ft}} = \text{cubic ft per ton.}$$

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per ton, or 20 pounds BeO; value per ton is calculated by multiplying assay in per cent BeO by price per unit.

Monazite is purchased on a flat price per ton basis rather than on the basis of the thorium or rare earth content. Therefore, calculate the per cent of monazite per ton of rock or gravel to determine the value, either by panning¹ or by determining the ratio of the thorium assay on the pure monazite to the thorium assay on a representative sample of the ore.² Since monazite is purchased as the pure mineral, the estimated cost of separation from the other constituents after mining must be subtracted from the gross value in the ground.

The above calculations provide, in most cases, a realistic figure of the value per ton at the market for uranium, vanadium, beryl, and monazite. However, for many other mine products, such as copper, for example, the value received will be considerably less than the value calculated in the above manner because of deductions made for smelter costs, loss in treatment, penalties, and other like expenses by the buyer.

WHERE TO GET HELP

The average prospector will not be able to achieve a complete evaluation of a discovery on his own. Depending upon his experience, he will want to seek help somewhere along the line. Even prospectors with a great deal of experience will often want their evaluation checked by someone else. Fortunately, help is easy to get. There are a great many services available and many different places from which to obtain them. Some services are free; others must be paid for.

Sample Examination and Assay. Probably the most important service and the one most frequently needed by the prospector is examination and assay of samples. This need ranges from the appeal of the amateur who collects a piece of rock at a place where his counter recorded a high reading, to the professional who has systematically sampled a discovery and needs several dozen samples assayed.

It is almost always possible to get a limited number of samples of a variety of metals examined or assayed free of charge or for a very nominal charge by taking or sending them to the school of mines of the state in which the discovery was made or to the State Bureau of Mines, Geological Survey, or some

$$\frac{\text{Weight of monazite recovered}}{\text{Weight of original sample}} \times 100 = \% \text{ monazite.}$$

$$\frac{\% \text{ monazite} \times \text{price per ton}}{100} = \text{value per ton of ore.}$$

$$^2 \text{ Thorium assay of pure monazite} = 5\%$$

$$\text{Thorium assay of ore} = 0.5\%$$

$$X = \text{monazite content of ore}$$

$$\frac{5}{100} = \frac{0.5}{x}; 5x = 50; x = 10\%.$$

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similar organization. There are also a few county organizations qualified to perform such service. There is an advantage to using these organizations for occasional samples from new finds because it is often possible to have a mineralogical study made that will reveal more about the sample than will a mere assay. On the other hand, large numbers of samples for routine assay should be taken to one of the many qualified commercial assayers. There is at least one in any town or city of any size in the western United States and in the larger midwestern and eastern cities. Officials of the school of mines or the state or local department of mines or geology will be glad to help locate one.¹ Prices for assays of the common metals range from \$1.00 to \$15.00, with most between \$3.00 and \$10.00.

A great many state agencies and most commercial assayers are also equipped to examine and assay radioactive samples. In addition, the Atomic Energy Commission has made arrangements for collecting information on samples showing radioactivity which are submitted to the Washington, D. C., laboratory of the U. S. Geological Survey or to the regional offices of the U. S. Bureau of Mines. Although this arrangement was made primarily for uranium assays, tests for thorium are also made. The Atomic Energy Commission's instructions concerning submission of samples to the Geological Survey and Bureau of Mines are reprinted in Appendix V. Samples that are not radioactive or large numbers of samples should be handled as suggested in the paragraph above. The local offices of the U.S.G.S. and of the Commission's Division of Raw Materials are always glad to make preliminary evaluations of samples for prospectors.

Property Examination and Professional Advice. Another important type of aid sought by many prospectors is that of examination of the discovery they have made, expert advice on its importance, and what should be done next. This problem is handled in much the same way as the assay of samples, although it is a much bigger job. The same state and local organizations who assay samples will often be willing to send a geologist or engineer to look at a property free of charge *if* the prospector can present some evidence that his find warrants investigation. Such evidence will most likely be a sample showing appreciable mineralization and a description of the deposit from which it was taken. There are also consulting geologists and engineers who, like the commercial assayers, can be found in most western towns and cities and in the major cities elsewhere in the country. They advertise in the mining magazines, and the state or local official concerned with mining will know of several.

¹ U. S. Bureau of Mines Information Circular No. 7523 lists all commercial assayers in the United States and is available free of charge from:

Publications Distribution Section
U. S. Bureau of Mines
4800 Forbes Street
Pittsburgh 13, Pennsylvania

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Consultants are expensive. They charge from \$25 to \$500 a day, with the average charge from \$50 to \$100. For this reason they are not often engaged for a preliminary examination of a raw prospect, but rather for detailed evaluations of discoveries which are already thought to have considerable promise. Because of the government's extreme interest in uranium, and because geological and mining experience with uranium has not been as widespread as with most other metals, the Atomic Energy Commission and the Geological Survey try to examine free of charge any discovery, the preliminary information on which appears significant. Just like the state and local agencies, however, they want some evidence that the time of their geologists and engineers will be well spent. The Atomic Energy Commission and the Geological Survey have this to say on the subject in their booklet *Prospecting for Uranium*:

The Geological Survey and Atomic Energy Commission receive many reports that uranium has been discovered, and they also receive many requests to have field representatives examine properties. A representative is sent where strong evidence exists that uranium does occur in sufficient amounts to be of interest to the Commission. Before a prospector requests that a representative be sent to examine a purported uranium deposit, he should submit a representative sample to a laboratory equipped to examine it and to test it for radioactivity.

If the sample is submitted to the Geological Survey or to the Bureau of Mines in accordance with the instructions given in Appendix V, and if it is of interest from the standpoint of uranium content, an examination by either the Survey or the Commission will be arranged automatically within a reasonable time, depending upon the degree of interest in it and the availability of field personnel. If a prospector believes he has an important find and wishes to speed up arrangements for the field examination, he should have one or more assays made himself and take the assay report to the nearest field office of the Commission or Geological Survey, together with additional samples for inspection and all the information he can develop on his own concerning his discovery. If the Commission or Survey geologists agree with him as to the probable importance of the discovery, they will attempt to arrange for an examination very soon thereafter.

The Atomic Energy Commission has been somewhat less interested in thorium, and when samples indicate that thorium is the principal constituent, field examinations may not be so readily arranged. However, if the information indicates a discovery of considerable importance, an examination will probably be made when it can be fitted into the schedule. Since most thorium deposits contain the rare earths, the prospector may wish to contact directly one of the companies engaged in extraction and sale of rare earths, several of which are interested in examining new deposits. These companies are listed in Appendix XI.

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The Commission is not, at this writing, interested in examination of beryllium deposits, but the examination of a promising discovery can probably be arranged with the local office of the Geological Survey or Bureau of Mines as part of their regular activities on all mineral resources. The prospector may also wish to write to one of the companies listed under beryllium in Appendix XI.

It should be emphasized again that there is no reason why private or state geologists or engineers cannot make quite adequate examinations of uranium, thorium, or beryllium prospects. Any qualified and reliable geologist or mining engineer who does run up against something new to him during an examination will know where to go to get the answer. No matter what metal is involved, good, sound geological and engineering practice and knowledge are the primary requirements.

Financial Aid. The prospector may obtain financial aid for the exploration and development of a discovery from private sources or by government assistance. Although it may often be more difficult to obtain, private financing is frequently simpler and more satisfactory, since it eliminates the often unavoidable "red tape" of many kinds of government assistance.

Private financial help is usually obtained in one of four ways: (1) An interest in the prospector's discovery can be sold to a person or persons with the necessary capital at a price sufficient to pay for fully exploring the deposit and putting it into production. There are usually a number of such people available if the property looks good enough. (2) The property can be sold outright, sometimes with the reservation of a certain percentage of the future earnings. (3) A stock company can be formed and shares sold. This requires a good knowledge of the principles of finance as well as of the government's regulations concerning such ventures, and is neither recommended nor possible for the average prospector, unless he can acquire a partner or associate who is qualified to handle the problems involved. (4) A loan can sometimes be arranged with the local bank.

The principal government agency established to provide financial assistance is the Defense Minerals Exploration Administration (DMEA), a part of the U. S. Department of the Interior. The DMEA finances exploration and development of worthy deposits of strategic minerals whose discoverers or owners do not have and cannot find sufficient means to pay for the work themselves. This is a temporary emergency program, however, begun in 1950, and it can be terminated at any time that the government determines it is no longer required.

DMEA provides financial aid in the form of loans of from 50 to 90 per cent of the cost of approved exploration programs for a selected group of metals and minerals.¹ The proportion of the cost provided by the government depends upon

¹ Complete information can be obtained from the Defense Minerals Exploration Administration, U. S. Department of the Interior, Washington 25, D. C., or from local U. S. Geological Survey or U. S. Bureau of Mines offices.

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the metal or mineral and may change from time to time, but in the case of uranium, thorium and beryllium properties, it is now 75 per cent. If ore is subsequently produced from the property within 10 years of the date of the loan, the government is repaid on a royalty basis ranging from $1\frac{1}{2}$ to 5 per cent of the net proceeds. Loans are made on the basis of the strategic importance of the mineral involved; the geological probability of making a significant discovery; the availability (to the prospector) of manpower, equipment, materials, and supplies to carry on the project; the availability of water and power; and the operating experience and background of the applicant. In view of this last consideration, it is important for the prospector, if he is not experienced himself, to find someone who has had mining experience to take charge of the work.

It is important to note that loans are not likely to be made on the basis of surface showings alone. Enough work should have been done to give some indication of what might be expected from further exploration.

The types of financial aid referred to above are for exploration and development of a discovery after it has been made, and usually after some work has been done on it. Unfortunately, there is no provision for government financial aid for prospecting itself—*grubstaking* as it is commonly called.¹ The centuries-old custom of private grubstaking has not been completely abandoned, however, and it is still possible in some of the western mining camps to find an individual who is willing to contribute a few dollars or a few weeks' supply of food to a reliable prospector in return for a share in anything he finds.

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¹ See Appendix XII for grubstaking provisions in Canada.

XXIII

MARKETING URANIUM, THORIUM, BERYLLIUM AND ASSOCIATED ORES

The end point of prospecting is, of course, to sell what is found. The prospector who makes a discovery often may not actually develop it and mine and sell the ore himself, but someone will. It is important, therefore, to know something about the market for the materials discovered and how to go about selling them. In fact, although this is the last step in the process of prospecting, and it has been made the subject of the last chapter in this book, a knowledge of the market for the materials sought—what the demand for them is and what they will bring—is probably the first thing the prospector should acquire. Unless he knows the value of what he is looking for, he is operating in the dark.

The ores of thorium and beryllium, and other ores associated with them and with uranium, with the exception of gold and silver, are sold on the open market at prices generally governed by the laws of supply and demand. The sale and purchase of thorium-bearing ores in the United States require licenses from the Atomic Energy Commission. Beryllium-bearing ores are not subject to licensing.

Uranium ore is handled differently, although the only real difference is one that benefits the prospector and mine operator. The government guarantees a minimum price for uranium ores for a definite period of time, so that uranium is in much the same category as gold which the government will buy at \$35 a troy ounce. In the case of uranium, however, the government guarantees a minimum price for the raw ore as well as for the refined product. This is an added advantage to the prospector or small operator who cannot refine the ore himself.

URANIUM

Uranium may be sold either to the U. S. Atomic Energy Commission directly, or to any individual or company within the United States, provided both the seller and the buyer have been licensed by the Commission. The Commission has issued a number of circulars, announcements, and regulations (see Appendices IX and XI) containing detailed instructions on how to sell uranium ores, the prices and special allowances paid for them, the bonus payments, and the licensing procedures. In addition, information on procedures can be obtained

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at any uranium ore-buying station or mill. Licenses are issued automatically for deliveries of ores to these purchase depots. Following is a summary of the information in the circulars and announcements on the sale of uranium ores and refined products:

1. Guaranteed minimum prices, effective through March 31, 1962, for carnotite-type and roscoelite-type ores of the Colorado Plateau area, assaying 0.10 per cent U_3O_8 and more and meeting required specifications are as follows (Circular No. 5, Revised):

| <i>U₃O₈ Assay, Per Cent</i> | <i>Payment per Pound of U₃O₈ Contained in Ore</i> |
|---|---|
| 0.10..... | \$1.50 |
| 0.11..... | \$1.70 |
| 0.12..... | \$1.90 |
| 0.13..... | \$2.10 |
| 0.14..... | \$2.30 |
| 0.15..... | \$2.50 |
| 0.16..... | \$2.70 |
| 0.17..... | \$2.90 |
| 0.18..... | \$3.10 |
| 0.19..... | \$3.30 |
| 0.20 and more..... | \$3.50 |

Vanadium: \$0.31 per pound of V_2O_5 contained in the ore up to a maximum of 10 pounds V_2O_5 for each pound of U_3O_8 .

Premiums: \$0.75 per pound for each pound of U_3O_8 in excess of 4 pounds U_3O_8 per short ton (2,000 pounds) of ore (4 pounds per ton = 0.20 per cent); an additional \$0.25 per pound for each pound in excess of 10 pounds U_3O_8 per short ton (0.50 per cent).

Allowances: Development allowance of \$0.50 per pound U_3O_8 ; haulage allowance \$0.06 (6¢) per ton per mile from mine to purchase depot; maximum 100 miles (\$6.00 per ton of ore).

Carnotite- and roscoelite-type ores of the Colorado Plateau area are purchased at the above prices at the following mills and ore-buying stations:

| <i>Location</i> | <i>Buyer</i> |
|--------------------------------|----------------------------------|
| Bluewater (Grants), New Mexico | Anaconda Copper Mining Co. |
| Shiprock, New Mexico | American Smelting & Refining Co. |
| Monticello, Utah | American Smelting & Refining Co. |
| Durango, Colorado | Vanadium Corporation of America |
| Grand Junction, Colorado | Climax Uranium Company |
| Naturita, Colorado | Vanadium Corporation of America |
| Rifle, Colorado | United States Vanadium Company |
| Uravan, Colorado | United States Vanadium Company |
| Salt Lake City, Utah | Vitro Chemical Company |
| Moab, Utah | American Smelting & Refining Co. |

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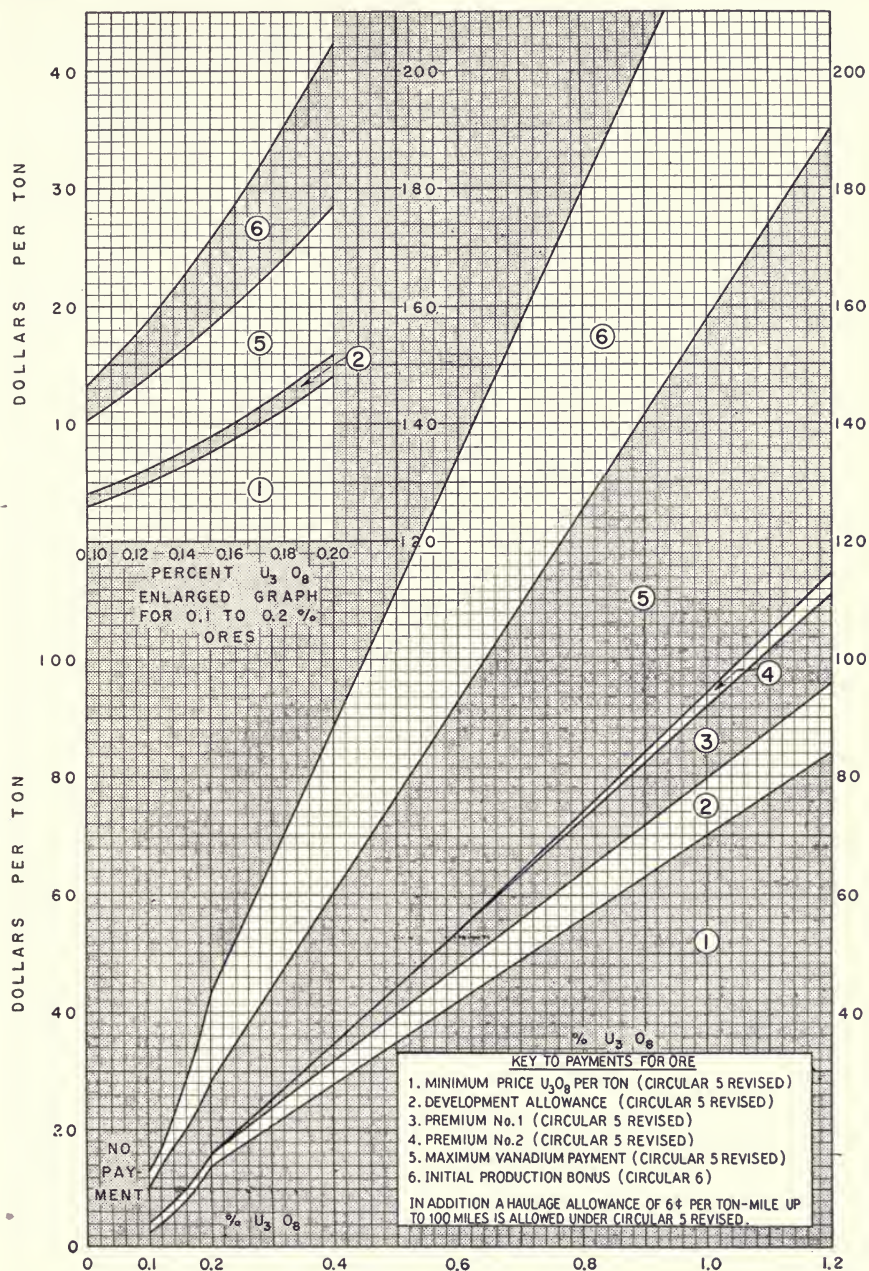


PLATE XXX. Uranium Ore Price Graph. Courtesy Engineering & Mining Journal.

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2. Markets for other types of ores and ores from other locations on the basis of above schedule for carnotite- and roscoelite-type ores of the Colorado Plateau area have been provided:

a. Carnotite ores of the Black Hills area can be sold at Edgemont, South Dakota, to the American Smelting and Refining Company.

b. The limestone ores of the Grants district, New Mexico, can be sold without penalty for high lime content to Anaconda Copper Mining Company, Bluewater, New Mexico.

c. Ores of the Marysvale, Utah, district, will be purchased at Marysvale by arrangement with Vitro Chemical Company, 600 West 33rd Street South, Salt Lake City; American Smelting and Refining Company, P. O. Box 986, Grand Junction, Colorado; or U. S. Atomic Energy Commission, P. O. Box 270, Grand Junction, Colorado.

d. Copper-uranium ores can be sold at Marysvale, Utah, or Monticello, Utah, through arrangements with American Smelting and Refining Company or the Atomic Energy Commission; at Hite, Utah, through arrangements with Vanadium Corporation of America; or at certain other places for shipment to Salt Lake City through arrangements with Vitro Chemical Company. Contracts may provide for payment for some of the copper in the ore on the basis of a deduction of 1 per cent from the copper assay and payment for 40 per cent of the remaining copper at the current market price. (This follows normal custom smelter procedure taking into account smelting costs and losses.) No payment will be made for the small amount of vanadium or other metals in these ores.

e. Pitchblende ores of the Colorado Front Range area and complex ores from the Idaho, Montana, Wyoming, Nevada, and southern Arizona areas can be sold through special arrangement with the Vitro Chemical Company, Salt Lake City, Utah, or with the U. S. Atomic Energy Commission, Grand Junction, Colorado. Minimum U_3O_8 content acceptable may be higher than the 0.10 per cent for other ores and will be a matter for negotiation along with payment for other metals in the ore, freight charges, etc.

3. A bonus, effective through February 28, 1957, for initial production (Circular No. 6, Revised) providing the following: Bonus payments equal to and in addition to the guaranteed minimum prices for each pound of U_3O_8 in acceptable ore delivered to qualified mills or ore-buying stations from eligible new mining properties up to and including the first 10,000 pounds. Maximum bonus payment, is, therefore, \$3.50 per pound for 10,000 pounds, or \$35,000. The bonus is paid upon application to the Commission (Grand Junction, Colorado) and after certification of the mine. It is not paid at the mills or buying stations.

4. A bonus of \$10,000, effective until April 11, 1958, for the discovery of a new deposit and the production therefrom of the first 20 short tons of uranium

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ore or mechanical concentrate assaying 20 per cent or more U_3O_8 . This bonus is a separate incentive to stimulate prospecting for new high-grade vein deposits, and the requirements are high in terms of grade of ore (Circular No. 2).

5. A guaranteed minimum price effective until April 11, 1958, of \$3.50 per pound for uranium oxide contained in domestic ores or mechanical concentrates assaying at least 10 per cent U_3O_8 (Circular No. 1). This price is f.o.b. shipping point, less estimated cost of refining. Since this price was established, the more favorable schedules for much lower-grade ores have been established. The Commission would undoubtedly negotiate a price at least as good as those schedules for ores running 10 per cent U_3O_8 or better, as this circular requires.

6. A guaranteed minimum price effective until April 11, 1958, of \$3.50 per pound for uranium oxide contained in refined uranium products f.o.b. shipping point (Circular No. 1). This circular provides for negotiation of higher prices for refined products or ores or mechanical concentrates (see 5 above) based on production costs if the quantities available justify it. This procedure has been followed regularly for the refined products produced by western mills. No significant quantities of ores or mechanical concentrates of 10 per cent U_3O_8 or better have yet been produced in the United States.

If uranium ore of commercial grade is discovered in new areas not accessible to any of the present purchase depots and the quantity is sufficient to warrant it, arrangements will be made by the Commission to establish a buying station, build a mill, or otherwise arrange for its disposition.¹ It can readily be seen that items 1, 2, and 3 above, involving Commission Circulars 5 and 6, and related announcements are of primary interest to the prospector and mine operator. No payments have as yet been made under any of the other circulars.

All of the above prices are guaranteed *minimum* prices for a certain length of time. It does not mean they cannot be raised during that time or continued after it. Prices for ores of the carnotite-roscoelite-type have been raised twice since the schedule was originally established in 1948. Prices will undoubtedly be maintained at whatever level is required to guarantee an adequate supply of uranium, but they cannot be lowered during the term of the guarantee. The long-range future of uranium prices is, of course, dependent upon demand. However, since both military and peacetime applications are developing at an ever-increasing rate, there would seem to be little question of a continuing market at good prices.

All the Commission circulars and announcements apply to ores produced in the United States. The Commission will examine samples of foreign ores and

¹ In areas that are especially distant from a buying station, arrangements may be made for a limited time and a limited tonnage to move the ore to market through a written agreement wherein the rail haul costs are borne by the government. Such arrangements will be made by the Commission's Grand Junctions Operations Office, Grand Junction, Colorado.

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consider buying them at a negotiated price based on the prices for domestic ores if, under the regulations of the foreign government concerned, they can be delivered to the Commission.

THORIUM

There is no market for thorium ores as such at the present time. However, should a sufficiently large and rich deposit containing principally thorium be found, it is not unlikely that the Atomic Energy Commission would negotiate a contract for the purchase of the ore or a refined thorium product. In the meantime, the only mineral containing a significant amount of thorium for which there is a market is monazite, and this market is determined primarily by the need for rare earths.

The price of monazite is neither guaranteed nor controlled by the Atomic Energy Commission, since the Commission can obtain the thorium it requires by purchases of the excess thorium from monazite processing by companies interested primarily in the extraction and sale of the rare earths. Monazite prices, like those for most other minerals, are dependent upon supply and demand and are subject to the variations in the economy of the country, at least to some extent, although probably not as much as copper, lead, or zinc, to take just three examples. The price of monazite purchased in the United States rose steadily after 1940 from about \$60 a short ton to a high of about \$375, largely due to the fact that the supply was limited almost entirely to India and Brazil. As the price rose after the war, the low-grade deposits of Florida and Idaho became economic, and there is now considerable domestic production. At the same time, the important South African deposits were discovered. As a result of these two developments, the price has probably reached about its peak.

Because over-all production of monazite is relatively small and the need for it more constant than for many other raw materials, it is probably safe to assume that, unless a large need for thorium is developed by the Atomic Energy Commission or a very marked slump in the economy should occur, the price will be maintained in the \$300-\$400 per ton range for several years. Monazite prices are based on a relatively pure monazite concentrate, usually 95 per cent or better, with a total rare-earth oxide content of at least 60 per cent. Penalties apply for anything less than 60 per cent down to a minimum acceptable content of 50 per cent rare earths. Thorium content is not usually a factor. The operator who does not have the means of obtaining a 95 per cent monazite concentrate himself can usually arrange to have his crude product up-graded at the nearest magnetic separation plant, or to sell the crude to the operator at some negotiated price. Most monazite concentrates will meet the rare earth specifications.

Companies who may be interested in the purchase of monazite, and the

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agencies that sometimes buys it for the government stockpile, are listed in Appendix XI. Licenses for its sale, required by the Atomic Energy Commission because of thorium content, can probably be arranged by the buyer or can be obtained directly by writing the U. S. Atomic Energy Commission, Licensing Branch, 1901 Constitution Avenue, Washington 25, D. C.

BERYLLIUM

The sale of beryllium ore (beryl) is not controlled in any way by the Atomic Energy Commission and is dependent entirely upon supply and demand. The history of beryl is very similar to that of monazite. Since the early 1940's it has undergone a continual increase in price from about \$8 a unit to about \$45 a unit (1 per cent per ton or 20 pounds contained BeO) for a minimum content of 10 per cent BeO. Also like monazite, as the price rose, new sources of supply were developed. The most important new source so far has been southern Africa, but the price has now reached a point where the large, low-grade beryl-bearing granites of Arizona and Utah, and pegmatite ores of North Carolina, may become economic.

It is more difficult to predict future prices for beryl than for monazite, but it does not appear that the price will decline substantially.

Offers of beryl should be made to the companies listed in Appendix XI or to the Emergency Procurement Service, General Services Administration, Washington 25, D. C.¹

OTHER ASSOCIATED MINERALS AND METALS

The principal metals and minerals of value most likely to be found in commercial quantities along with atomic energy minerals are as follows:

In uranium deposits—vanadium, copper, lead, zinc, silver, gold, cobalt, nickel, manganese, fluorspar.

In thorium (placer) deposits—columbium, tantalum, ilmenite, rutile, zircon, gold, cassiterite.

In beryl deposits—columbite, tantalite, feldspar, mica, spodumene.

With the exceptions of gold and silver, which are sold at government-fixed prices of \$35 and \$0.90½ a troy ounce, respectively, and vanadium, for which the Atomic Energy Commission guarantees \$0.31 per pound of V₂O₅ in ore containing up to 10 pounds V₂O₅ per pound of U₃O₈, these associated metals and minerals are bought at prices that fluctuate from day to day. It is possible to get a general idea of what these materials are worth by studying the present and past prices. Up-to-date quotations on most of them can be found in *Engineering and Mining Journal*, *American Metal Market*, and other trade

¹ The present termination date for government purchases is June 30, 1957.

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Annual Averages—1897-1953

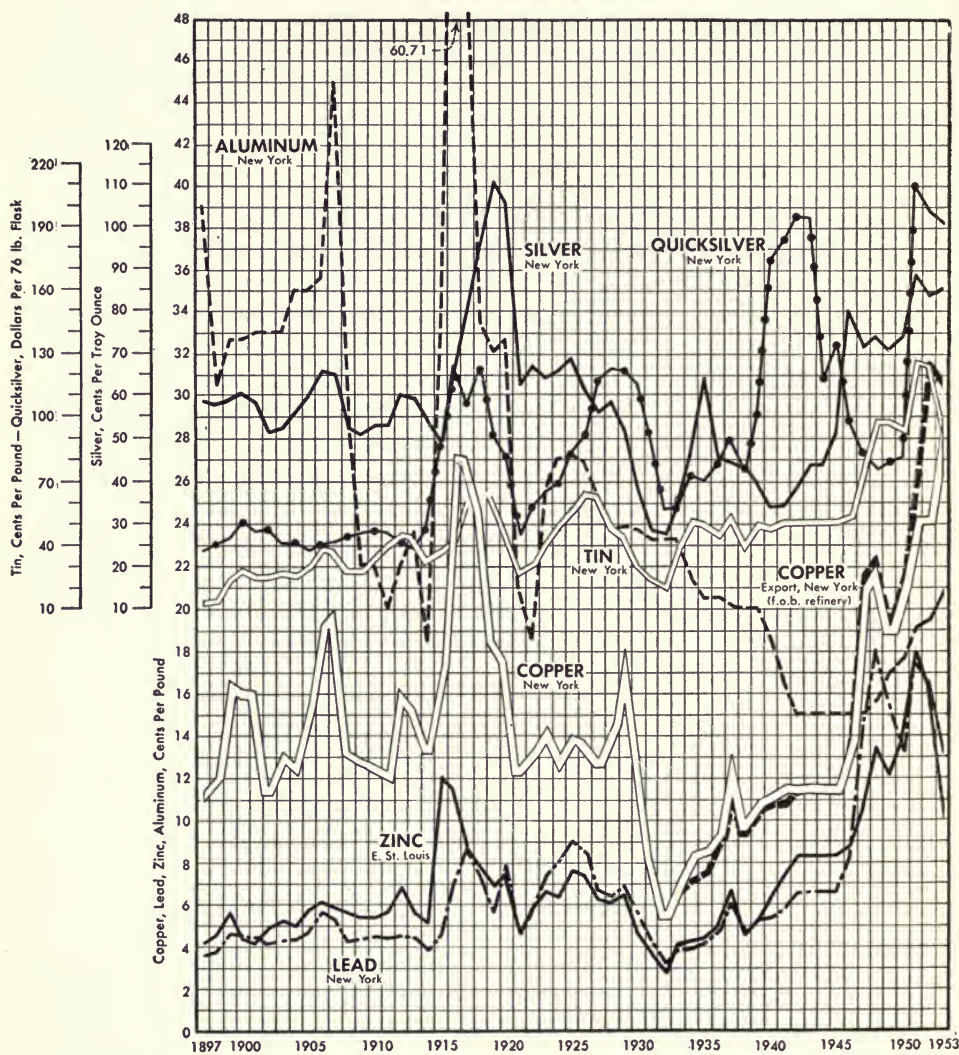


PLATE XXXIA. Engineering & Mining Journal Metal Prices. Courtesy McGraw-Hill Publishing Co. Inc., New York.

magazines, as well as in some newspapers. The prices listed for metals are usually net refining quotations. Information on deductions made for smelting costs, losses, etc., should be obtained from the nearest custom smelter. Prices quoted for minerals such as zircon, feldspar, columbite, etc., are the actual prices paid to the miner.

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Weekly Averages—1953

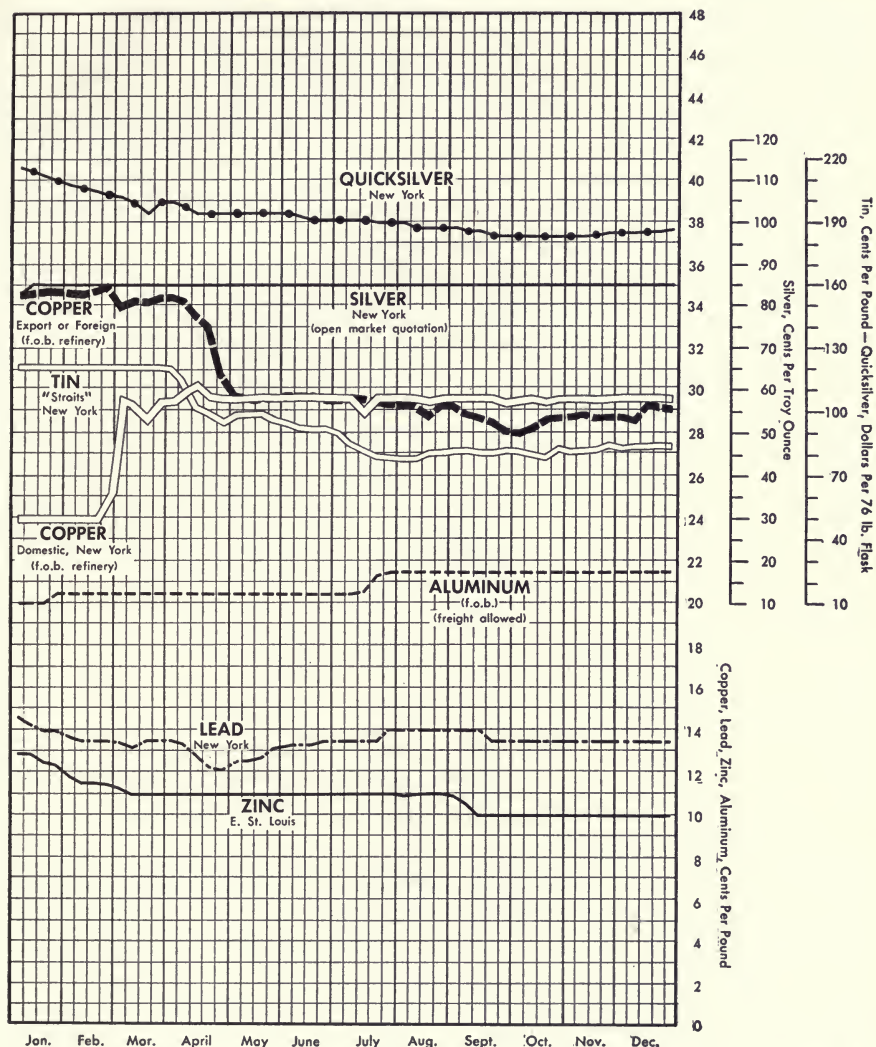


PLATE XXXIB. Engineering & Mining Journal Metal Prices. *Courtesy McGraw-Hill Publishing Co. Inc., New York.*

In 1952, the government became the largest purchaser of columbium and tantalum ores and concentrates through the following agents under a program guaranteed through 1956:

Fansteel Metallurgical Corporation, North Chicago, Illinois
 Wah Chang Corporation, New York, New York

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Kennametal, Inc., Latrobe, Pennsylvania

Emergency Procurement Service, General Services Administration, Washington 25, D. C.

Prices for these ores, depending upon specifications as to columbium and tantalum content and the relative proportions of each, vary from \$1.40 and up per pound of combined Cb_2O_5 and Ta_2O_5 in the ore to \$3.00 and up per pound of contained Ta_2O_5 in ore.

An incentive bonus of 100 per cent is offered for lots meeting specifications. Penalties are imposed for subspecification lots.

A general range of prices for other metals and minerals under normal conditions is given below in order to give the unfamiliar reader a "feel" of their value. It must be remembered that these prices can fluctuate widely.

| | <i>Minimum Metal Content (for Ores)</i> | <i>Price</i> |
|---------------------|---|--|
| Copper ¹ | — | \$0.15-0.25 per pound |
| Lead ¹ | — | \$0.10-0.15 per pound |
| Zinc ¹ | — | \$0.10-0.15 per pound |
| Cobalt | 8-13% | \$0.75-1.50 per pound of cobalt contained, f.o.b. Cobalt, Ontario |
| Nickel | Oxide sinter | \$0.35-0.55 per pound of nickel contained f.o.b. Copper Cliff, Ontario |
| Manganese | 46-52% | \$25-50 per short ton of ore f.o.b. U. S. ports or mines |
| Ilmenite | 56-60% TiO_2 | \$15-20 per ton f.o.b. Atlantic ports |
| Rutile | 88-94% TiO_2 | \$0.04-0.10 per pound c.i.f. New York |
| Zircon | 55-65% ZrO_2 | \$40-75 per ton f.o.b. Atlantic ports |
| Fluorspar | 50-95% CaF_2 | \$15-60 per ton |
| Spodumene | 6% LiO_2 | \$5-8 per unit |
| Feldspar | — | \$10-20 per ton |
| Mica | — | \$10 and up per ton, depending upon quality |

The presence of one of these materials in good quantity and grade in a deposit of atomic energy minerals may increase the value of the ore. If the prospector suspects the presence of these other valuable minerals or metals in his ore he should have assays made for them, estimate the possible additional value of the ore, and inquire whether the ore is of such a nature that all of the constituents can be recovered and payment received for them. If all the materials are not recoverable he may have to choose between selling his ore for uranium or, for example, for copper. In the latter case a license would be required if the uranium content were greater than 0.05 per cent.

¹ Prices of the metal. Copper payments would be on the basis of 40 per cent of the quoted price for the copper content less 1 per cent or 20 pounds per short ton. Lead and zinc would be figured on the same general basis.

Appendix I—Uranium Non-ore Minerals

SECONDARY MINERALS

This list includes only the better known secondary non-ore minerals. Most of them are primarily of interest to the scientifically minded prospector, the geologist, mineral collector, and student. Their identification is not usually important in the search for an ore deposit, although as a result of developments in 1952, 1953, and 1954, some of them, particularly becquerelite, uranocircite, parsonsite, phosphuranylite, zeunerite, kasolite, and uranospinite, are approaching the importance of ore minerals.

Gummite ($40\text{--}80\%$ U_3O_8). Gummite does not have a fixed chemical composition but is composed principally of uranium, lead, and water, together with varying amounts of barium, calcium, rare earths, thorium, and silicon. It is one of the most spectacularly colored uranium minerals, usually bright orange, orange-yellow, or yellow, but occasionally red, red-brown, or black; it has an orange, yellowish, brownish, or greenish streak. Although gummite does not qualify as an ore mineral, it is one of the common uranium minerals and is intimately associated with pitchblende and uraninite in both vein deposits and pegmatites wherever they have been exposed to weathering processes or to alteration by later hydrothermal solutions. Gummite normally has a dull, greasy luster but, occasionally, is glossy and brilliant; it does not fluoresce. Its hardness varies between 4 and 6, and it occurs in rounded masses and crusts surrounding pitchblende or uraninite. It occasionally replaces uraninite completely, taking on its cubic crystal form.

The occurrence of gummite is the same as for pitchblende and uraninite. Among the secondary uranium minerals it is most closely associated with uranophane, autunite, and torbernite. Some of the best specimens of gummite, other than from Shinkolobwe where it was common, have come from the pegmatites of the Spruce Pine district, North Carolina, and the Ruggles Mine, Grafton, New Hampshire.

Becquerelite ($2\text{UO}_3 \cdot 3\text{H}_2\text{O}$; 80% U_3O_8). Becquerelite is an alteration product of uraninite and pitchblende previously known only in the oxidized zone of the Shinkolobwe mine; at Wolsendorf, Bavaria; and in the Cato Sells mine, Apache County, Arizona. It may also be present in con-

siderable quantity in the Big Indian Wash deposits and other deposits of the Colorado Plateau. It is amber colored, with a greasy luster and a yellow streak. Its hardness is 2-3, and its specific gravity, 5.2. It occurs in tabular crystals and does not fluoresce.

Fourmarierite ($\text{PbO} \cdot 4\text{UO}_3 \cdot 7\text{H}_2\text{O}$; 70% U_3O_8). Fourmarierite is red to golden-red or brown with a diamond-like luster. Its hardness is 3-4, and its specific gravity, 6. It occurs in tabular crystals and does not fluoresce. Known occurrences of fourmarierite have been limited to the Shinkolobwe mine.

Curite ($2\text{PbO} \cdot 5\text{UO}_3 \cdot 4\text{H}_2\text{O}$; 70% U_3O_8). Curite is an alteration product of uraninite found principally in the Belgian Congo in association with torbernite, becquerelite, and fourmarierite. It is orange-red with a diamond-like luster and an orange streak; its hardness, 4-5; specific gravity, 7.2. It can be either massive or in aggregates of fine needles. It does not fluoresce.

Uranocircite and Meta-uranocircite ($\text{BaO} \cdot 2\text{UO}_3 \cdot \text{P}_2\text{O}_5 \cdot n\text{H}_2\text{O}$; 50% U_3O_8). Uranocircite and meta-uranocircite are hydrous barium, uranium phosphates with identical physical properties and differing only in the amount of H_2O present. They are yellow to yellow-green with a pale yellow or greenish-yellow fluorescence. They are soft (hardness, 2-2.5) and somewhat heavier than quartz (specific gravity, 3.5). They occur in the unusual secondary deposit in clay beds near Vinaninkarena, Madagascar and in the recently discovered deposits in sandstones in the Wind River Basin, Wyoming. They can be differentiated from autunite, which they closely resemble, by a positive test for barium.

Parsonsite ($2\text{PbO} \cdot \text{UO}_3 \cdot \text{P}_2\text{O}_5 \cdot 2\text{H}_2\text{O}$; 30% U_3O_8). Parsonsite is a hydrous lead uranium phosphate occurring in small, pale brown, tabular crystals or earthy masses. It has a pale brown streak, a greasy luster, and a specific gravity of 6.2. It is not known to fluoresce. Parsonsite was originally found in the Belgian Congo in association with kasolite and torbernite in the oxidized zones of the pitchblende veins. It has recently been found in quartz-fluorite-barite veins in granite in central France, in association with pitchblende, torbernite, autunite, kasolite, uranotile, and renardite.

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Renardite ($\text{PbO} \cdot 4\text{UO}_3 \cdot \text{P}_2\text{O}_5 \cdot 9\text{H}_2\text{O}$; 65% U_3O_8). Renardite is a hydrous lead uranium phosphate, very similar to parsonsite, occurring in very small, flat, yellow crystals with a greasy luster. It has a yellow streak, a hardness of 2-3, and a specific gravity of about 4. It is not known to fluoresce. It occurs principally in the Shinkolobwe mine.

Dumontite ($2\text{PbO} \cdot 3\text{UO}_3 \cdot \text{P}_2\text{O}_5 \cdot 5\text{H}_2\text{O}$; 50% U_3O_8). The physical properties and occurrence of dumontite are essentially the same as for renardite. In the United States, dumontite has been reported in the White Oak Mine, near Nogales, Arizona, with kasolite, uranophane, and autunite.

Phosphuranylite ($3\text{UO}_3 \cdot \text{P}_2\text{O}_5 \cdot 6\text{H}_2\text{O}$; 70% U_3O_8). Phosphuranylite is a uranium phosphate identified in the pegmatites of the Spruce Pine district, North Carolina; in the copper-uranium deposits of the White Canyon district, Utah; and in the Wind River Basin, Wyoming. It is a deep-yellow mineral that forms powdery crusts or coatings composed of masses of small, flat, square or rectangular crystals on fracture surfaces. It has a pearly luster, a yellow streak, a hardness of about 2-3, and a specific gravity of about 3.3.

Zeunerite and Meta-zeunerite ($\text{CuO} \cdot 2\text{UO}_3 \cdot \text{As}_2\text{O}_5 \cdot n\text{H}_2\text{O}$; 50% U_3O_8). Zeunerite and meta-zeunerite are hydrous arsenates of copper and uranium, identical in appearance to torbernite and with the same chemical formula, except that arsenic is substituted for phosphorus. They are not quite as heavy as torbernite, having a specific gravity of 3.2 as compared to 3.5 for torbernite. Zeunerite and meta-zeunerite have been identified in association with pitchblende in Saxony, at Joachimsthal, and at Cornwall, England; in the oxidized zones at Marysvale, Utah, and Urgeirica, Portugal, associated with autunite, torbernite, uranophane, and other secondary minerals; at the Monument No. 2 mine in the Navajo Reservation, Arizona, associated with carnotite and pitchblende; and in copper-tin deposits of the Seward Peninsula, Alaska. They are also probably present in the Wind River Basin, Wyoming.

Uranospinite and Meta-uranospinite ($\text{CaO} \cdot 2\text{UO}_3 \cdot \text{As}_2\text{O}_5 \cdot n\text{H}_2\text{O}$; 50% U_3O_8). These minerals belong to the torbernite, autunite, zeunerite, uranocircite family, arsenic sub-

stituting for the phosphorus of autunite or calcium for the copper of zeunerite. They have the same appearance and other physical properties as autunite, except for a slightly higher specific gravity (3.45 as compared to 3.1). Their occurrence is similar to that of zeunerite, and they occur together in the same manner as torbernite and autunite. They were tentatively identified in late 1953 as important constituents of the newly discovered deposits of the Wind River Basin, Wyoming.

Zippeite ($2\text{UO}_3 \cdot \text{SO}_3 \cdot n\text{H}_2\text{O}$; 70% U_3O_8). Zippeite is a rare hydrous uranium sulfate reported in association with pitchblende and other secondary minerals at Joachimsthal and in the Kirk Mine, Gilpin County, Colorado. It has also been identified with johannite in efflorescent coatings on the mine walls at the Happy Jack copper-uranium deposit, White Canyon, Utah. It is an earthy, orange to yellow, powdery mineral with a pale yellow streak and a dull green or yellowish-green fluorescence. Its hardness is 2-3, and its specific gravity is about 3.5.

Johannite ($\text{CuO} \cdot 2\text{UO}_3 \cdot 2\text{SO}_3 \cdot 7\text{H}_2\text{O}$; 55% U_3O_8). Johannite is a copper uranium sulfate that occurs intimately associated with zippeite. It is yellow to green to black, with a glassy luster and a pale yellow to green streak. It occurs in small, lath-like crystals arranged concentrically, and has a hardness of 2-2.5 and a specific gravity of 3.25.

Uranotile (Beta-uranotile) ($\text{CaO} \cdot 2\text{UO}_3 \cdot 2\text{SiO}_2 \cdot 6\text{H}_2\text{O}$; 60% U_3O_8). Uranotile, or beta-uranotile, as it is properly called, is a calcium uranium silicate, occurring in chrome-yellow or orange-yellow velvety coatings or radial tufts of lath-like or needle-like crystals. It has a pearly luster, a pale yellow streak, a hardness of 2-3, and a specific gravity of 4. It does not fluoresce. The occurrence of uranotile is similar to that of uranophane. It occurs with pitchblende, torbernite, autunite, uranophane, and the lead-uranium phosphates in oxidized pitchblende veins at Joachimsthal, Czechoslovakia; at Urgeirica, Portugal; and in the Massive Central, central France. It occurs at Wolsendorf, Germany and in a pegmatite at Bedford, New York, and has also been identified with uraninite from the Deer Park mine, Mitchell County, North Carolina.

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Soddyite ($5\text{UO}_3 \cdot 2\text{SiO}_2 \cdot 6\text{H}_2\text{O}$; 80% U_3O_8). Soddyite is a yellow to greenish-yellow uranium silicate with a dull, pearly luster and pale yellow streak, having a hardness of 3-4 and a specific gravity of 4-6; it does not fluoresce. Soddyite occurs as minute prismatic crystals closely associated with curite, kasolite, and uranophane at Shinkolobwe.

Kasolite ($\text{PbO} \cdot \text{UO}_3 \cdot \text{SiO}_2 \cdot \text{H}_2\text{O}$; 45% U_3O_8). Kasolite is a hydrous lead uranium silicate with yellow to yellow-brown color, pale yellow streak, and resinous to greasy luster. It has a hardness of 4-5 and a specific gravity of nearly 6. It occurs as minute prismatic or tabular crystals in radiating bunches in association with curite, soddyite, and uranophane at Shinkolobwe and in the deposits of central France. It is also reported from Urgeirica, Portugal, Marysvale, Utah, and from the White Oak mine near Nogales, Arizona.

Rauvite ($\text{CaO} \cdot 2\text{UO}_3 \cdot 5\text{V}_2\text{O}_5 \cdot n\text{H}_2\text{O}$; 25%

U_3O_8). Rauvite is a hydrous calcium uranyl vanadate occurring in small quantities in the carnotite deposits of the Colorado Plateau area. It is particularly known at Temple Mountain, Utah, and at the Monument No. 2 mine, Apache County, northern Arizona. Rauvite is a very soft, dull purple mineral with a light yellow-brown streak and specific gravity of about 4. It has no crystal form, occurring in botryoidal or massive structures.

Vandenbrandeite ($\text{CuO} \cdot \text{UO}_3 \cdot 2\text{H}_2\text{O}$; 65% U_3O_8). Vandenbrandite is a dark green to almost black hydrated oxide of copper and uranium usually occurring in small flattened plates, often in parallel clusters. It has a hardness of 4, a specific gravity of 5 and a green streak. Vandenbrandite is found in the Belgian Congo associated with other secondary copper and uranium minerals. It is also present in small amounts in some of the copper-uranium deposits of the Colorado Plateau.

PRIMARY MINERALS

Although there are a large number of rare primary minerals, only the minerals likely to be encountered in the field by the prospector will be mentioned. All of these minerals are complex in composition and often contain a variety of elements in varying proportions. Consequently, it is possible to describe only an approximate chemical composition for most of them. The uranium and thorium contents given here are also approximate, since the content of both of these elements may vary significantly. None of these minerals fluoresce. They generally occur in irregular masses of well-formed crystals and range in color from dark brownish-red to black. Generally lighter in weight than pitchblende, they have about the same hardness but a less pitch-like and more glassy luster.

Brannerite (oxide of uranium and titanium; minor calcium, rare earths, thorium and iron; 40% U_3O_8 ; 14% ThO_2). Brannerite is jet black when fresh, but when exposed for any length of time to weathering it may alter to a brown, yellow-brown, or olive-green. It has a glassy luster and a greenish-brown streak when fresh, and a greasy or resinous luster and yellowish-brown streak when altered. It may form solid prismatic crystals up to 4 or 5 inches

across. Brannerite fractures like glass, leaving a curved surface, has a hardness of 4-5 and a specific gravity of 4.5-5.5.

Brannerite was originally noted primarily for its occurrence in placer deposits in central Idaho and in a pegmatite near Fuente Obejuna,¹ Cordoba, Spain. However, it has been recently reported in cobalt veins at Bou Azzer in the Atlas Mountains, Morocco. A high-thorium variety of brannerite, tentatively called absite, was discovered in 1951 near Crocker's Well, South Australia, by geophysicists of the South Australia Department of Mines during an aerial radioactivity survey. There it occurs in irregular masses and scattered crystals in fracture zones in close association with biotite mica in a white granite locally almost free of quartz.

Pyrochlore-Microlite (complex oxides of columbium, tantalum, sodium, and calcium; occasional fluorine; up to 15% U_3O_8). Pyrochlore and microlite are minerals with similar physical properties, whose chemical compositions vary, particularly with respect to the relative amounts of columbium and tantalum present. Pyrochlore is rich in columbium, whereas microlite is rich in tantalum. The minerals may

¹ Formerly Fuenteovejuna.

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occur in a variety of colors from colorless to pale yellow, brown, reddish, or green to black, and display a glassy or resinous luster. The darker colors are usually characteristic of pyrochlore. These minerals occur as small grains or irregular masses, sometimes with an octahedral outline, embedded in other minerals. They fracture unevenly or splinter and have a colorless to pale yellow or brownish streak and a hardness of 5-6. The specific gravity may vary from 4.2 to 6.4, increasing with the tantalum content.

Pyrochlore, containing about 15% U_3O_8 and titanium oxide, is common in pegmatites near Hybla, eastern Ontario, Canada. In recent years an extensive deposit of high pyrochlore content granite has been developed in Nigeria for the eventual production of columbium and possibly by-product uranium. Similar granite deposits, though not as rich, are known in New England. Varieties particularly rich in uranium are called *hatchettolite* or *ellsworthite*. Micro-lite is found with the lithium minerals, spodumene and lepidolite, in pegmatites at the Brown Derby mine, Gunnison, Colorado, and at the Harding mine, near Las Vegas, New Mexico. It is associated with albite (feldspar), quartz, columbite, fluorite, and monazite in pegmatites near Amelia Court House, Virginia. Pyrochlore and microlite are also known in Norway, Sweden, Portugal, Western Australia, Finland, Madagascar, Greenland, Southern Rhodesia, and Brazil, as well as in Wisconsin, North Carolina, California, Maine, and Massachusetts.

Fergusonite¹ (columbate-tantalate of the rare earths with minor uranium, thorium, calcium, and titanium; 0-8% U_3O_8). Fergusonite occurs in tapered prismatic crystals of varying shades of brown to black, or it may be altered to a yellow-green color. It has a pale yellow to brown or greenish-gray streak, a glassy luster when fresh and a greasy to earthy luster when altered, an irregular fracture, a hardness of 5.5-6.5 (softer when altered), and a specific gravity of 4 to 6, depending upon the tantalum content and degree of alteration. (High tantalum—high specific gravity; high alteration—low specific gravity.) Fergusonite occurs in pegmatites with other columbium, tantalum, and rare earth

minerals. The richest occurrences known are in the pegmatite deposits of Madagascar. It is also known in Norway, Sweden, Japan, and in the United States in Amherst County, Virginia, and Barringer Hill, Llano County, Texas. A variety occurring in gold placers derived from pegmatites in Burke County, North Carolina, is known as *rutherfordite*, and the high-tantalum species, *formanite*, occurs with monazite, euxenite, and cassiterite in placer deposits in the Cooglegong district, Western Australia. Fergusonite is also present in the heavy mineral placers of central Idaho, Korea, and Malaya.

Samaraskite (a columbate-tantalate of the rare earths, uranium, thorium, calcium, and iron; 9-21% U_3O_8). Samarskite usually occurs in rather large, rough, black or dark brown crystals lacking definite form, and alters to a gray or yellowish color. It has a dark brown to black streak when fresh and a gray, yellow, or brown streak when altered; a glassy luster when fresh and a greasy or resinous luster when altered; a conchoidal fracture, hardness of 5-6, and a specific gravity of 4-6.

Samaraskite occurs in pegmatites with columbite, zircon, uraninite, monazite, mica, feldspar, topaz, beryl, and quartz in the U.S.S.R., Norway, Sweden, Madagascar, Belgian Congo, Brazil, and Canada, and widely throughout the United States. The better-known localities in the United States are the Spruce Pine district, Mitchell County, North Carolina; Glastonbury, Connecticut; Topsham, Maine; Sappington mine, Madison County, Montana; Devil's Head Mountain, Colorado; and Ohio City, Gunnison County, Colorado. A high uranium (21% U_3O_8) variety called *ishikawaite* occurs near Ishikawa, Iwaki Province, Japan. Samarskite is also probably present in the heavy mineral placers of central Idaho, Korea, and Malaya.

Euxenite-Polycrase (titanium, columbium, tantalum, oxides with uranium, thorium, and the rare earths; 1-20% U_3O_8). This is another mineral series like pyrochlore-microlite in which euxenite represents a ratio of titanium to columbium and tantalum of three to one or less and polycrase a ratio greater than three to one.

¹ Fergusonite forms a series with a rare high-tantalum species called *formanite* in a manner similar to the pyrochlore—microlite series.

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Euxenite and polycrase occur in irregular masses, usually with only vague crystalline form. They are jet-black in color, becoming chocolate-brown to yellow by alteration. They have a pale yellow to brown streak, a glassy luster (greasy or earthy when altered), a glass-like fracture, a hardness of 5.5-6.5, and a specific gravity of 4 to 5.8.

Euxenite and polycrase are very hard to distinguish from samarskite. However, euxenite and polycrase occur commonly with ilmenite and other titanium minerals, whereas samarskite does not; otherwise the occurrences of these minerals are the same. They are known in Norway, Madagascar, Western Australia, Belgian Congo, South Africa, Brazil, Canada, and the United States. Euxenite occurs at Morton, Delaware, and polycrase near Marietta, South Carolina; Zirconia, Henderson County, North Carolina; and at Barringer Hill, Texas. It is undoubtedly present in the pegmatites and placer deposits of many localities in the eastern and mountain states and represents the principal uranium mineral in the placer deposits at Bear Valley, Idaho.

Betafite (an oxide of columbium, titanium, and uranium with minor calcium, iron, rare earths, and tantalum; 15-27% U_3O_8). Betafite occurs in octahedral crystals, black to greenish-brown when fresh, yellow to yellow-brown by alteration. It has a glassy to submetallic luster, becoming greasy with alteration; a dark brown to yellow-brown streak; a glass-like fracture; a hardness of 4-5.5, depending upon degree of alteration; and a specific gravity of 3.75-5.25, depending on the columbium content (higher) and degree of alteration (lower).

Betafite is found in pegmatite deposits principally in Madagascar but also in Norway, Sweden, and U.S.S.R. It is associated with euxenite, fergusonite, allanite, columbite, and occasionally beryl, zircon, and garnet.

Columbite-Tantalite [columbium and tantalum oxides of iron and manganese; variable from (Fe, Mn) $O \cdot Cb_2O_5$ to (Fe, Mn) $O \cdot Ta_2O_5$; 0-0.6% U_3O_8]. Columbite and tantalite are the principal columbium and tantalum ore minerals. Columbium is in great demand for the manufacture of stainless steel and high-temperature-resistant alloys for jet engines, gas turbines, etc. Tantalum is used as the pure metal for objects

which must have a very high corrosion resistance. Pure columbite contains about 75% columbium oxide (Cb_2O_5), and pure tantalite contains about 80% tantalum oxide (Ta_2O_5). Columbite-tantalite contains varying amounts of the two elements between these two extremes. The uranium content is small, varying from 0 to 0.6% U_3O_8 . The minerals are mentioned here only because they are of commercial importance and relatively common in pegmatite and placer deposits and may be confused with other columbium-tantalum minerals with higher uranium content. The fact that these minerals are of commercial importance in themselves, of course, also increases the possibility that eventually they might become a by-product source of uranium.

Columbite and tantalite occur as black, brownish-black, or reddish-brown crystals of a prismatic, sometimes rectangular or tabular shape, and as massive material without apparent crystal form. They have a black, brownish-black, or dark red-brown streak, submetallic to diamond luster, hardness of 5.5-6, and specific gravity of 5.2 to 8, increasing with the tantalum content. They occur with the same mineral associations as the other refractory uranium-bearing minerals. When they occur in mineable concentrations, they are often associated with beryl, as in Brazil (particularly the states of Paraíba and Rio Grande do Norte), which is an important source of tantalum. The principal commercial sources of columbite are the Belgian Congo and Nigeria, where it is produced in conjunction with tin mining.

Thucholite (uranium-bearing hydrocarbon; minor thorium, rare earths, and silica; 2-8% U_3O_8). Thucholite is a rare, jet-black, coal-like mineral occurring in irregular nodules in pegmatites, usually in association with uraninite and cyrtolite (variety of zircon). It has a brilliant luster, a glass-like fracture, a hardness of 3.5-4, and a specific gravity of 1.78. It is usually found embedded in feldspar, quartz, or mica, where it may replace uraninite and has been identified in pegmatites at Parry Sound, Ontario, and at Buckingham, Quebec. Thucholite also occurs in an unusual manner at the Black King and White Spar properties near Placerville, Colorado, in vein-type deposits associated with copper, lead, and zinc sulfides.

It is probable that thucholite is associated with a variety of occurrences of uranium minerals that contain hydrocarbons, particularly the carnotite-asphaltite deposits at Temple Mountain, Utah; the

pitchblende deposits at Lake Athabaska, Saskatchewan, Canada; and the uraninite-bearing Witwatersrand gold ores of South Africa.

Appendix II—Other Thorium Minerals

Xenotime $[(Y,Er)_2O_3 \cdot P_2O_5]$. Xenotime is a rare mineral similar to monazite, the rare earths yttrium and erbium substituting for the cerium of monazite. It occurs in granite, gneiss, and pegmatites as prismatic crystals similar to zircon. In placer deposits it occurs usually as small, rounded grains like monazite, although often in the additional colors of pink, gray, yellow-green, or dark green. It has a hardness of 4-5 and a specific gravity of 4.5. It contains usually less thorium than monazite (2-5 per cent), but up to 3 or 4 per cent uranium.

Xenotime commonly occurs in varying amounts as a minor constituent in most monazite-bearing placers, the pink or green color most often distinguishing it. It is particularly known in the United States in the gold placers near Cartersville, Georgia, and in the monazite and gold-bearing placers of Burke, Henderson, Alexander, and Mitchell counties, North Carolina. Its mineral associations are the same as those of monazite.

Zirkelite (oxide of calcium, iron, thorium, zirconium, and titanium). Zirkelite is an ore mineral of zirconium occurring principally in an oxidized hydrothermal deposit in igneous rocks at Jacupiranga, São Paulo, Brazil, along with zircon and baddeleyite. It may contain as much as 20 per cent ThO_2 , some of which is often replaced by uranium (up to 14 per cent U_3O_8) and by the rare earths. It occurs as black to brownish-black, flattened, octahedral crystals with a chocolate streak, submetallic to resinous luster, a hardness of 5.5-6, and a specific gravity of 4.3-5. Zirkelite also occurs in placer deposits with tourmaline, zircon, and monazite in Ceylon and Brazil.

Zircon ($ZrSiO_4$). Zircon is a very common mineral and the principal zirconium ore mineral, occurring in almost all granite, pegmatites, and granite-like rocks and commercially produced from placers, principally in Australia. It also occurs with zirkelite in Brazil and with monazite in the beach sands of Brazil and India, as well as in small quantities in almost all sands and

gravels throughout the world. It occurs in small, distinctive, glassy, four-sided or occasionally eight-sided prismatic crystals having pyramid-like points, commonly colorless to pale yellow but occasionally blue, green, or red. It has a glass-like fracture, a hardness of 7.5 (slightly harder than quartz), and a specific gravity of 4-4.7. Zircon will often fluoresce vividly in yellow or golden yellow. Some zircon (see cyrtolite and naegite) contains up to 5 per cent ThO_2 and up to 3 per cent U_3O_8 , although most contains less than 0.5 per cent ThO_2 and 0.2 per cent U_3O_8 .

Cyrtolite ($ZrSiO_4$ plus rare earths, U, Th). Cyrtolite is the high uranium, thorium, and rare earth-bearing zircon. It is softer (hardness 3-6), lighter (specific gravity, 3.6-4.1), and more deeply colored (reds and browns) than common zircon. In addition to its occasional occurrence with ordinary zircon in granite, pegmatite, and placer deposits, it is known specifically from pegmatites in Hastings County, Ontario; the Ruggles Mine, Grafton, New Hampshire; at Rockport, Maine; and in Madagascar.

Naegite ($ZrSiO_4$ plus Cb, Ta, U, Th). Naegite is a high columbium, tantalum variety of zircon or cyrtolite occurring in small amounts in pegmatite deposits and tin placers in Japan. Because of its thorium and uranium content and similar physical characteristics, it has sometimes been confused with thorite.

Baddeleyite (ZrO_2). Baddeleyite is the second most important ore mineral of zirconium. It is mined for its zirconium content at Jacupiranga, São Paulo, Brazil, and at Poco de Caldas, Minas Gerais, Brazil, together with zirkelite and massive zircon. It is also known as zirkite, brazilite, and caldasite. Baddeleyite occurs as tabular or fibrous crystals or in banded masses, colorless through yellow, green, red, brown to black, with glassy to greasy luster and white to brownish-white streak. It has a hardness of 6.5 and a specific gravity of 5.4-6. It may contain appreciable thorium

OTHER THORIUM MINERALS

and small amounts of uranium. Since baddeleyite and zirkelite are already mined for zirconium in Brazil, they could become a source of either uranium or thorium, but more likely the former because of its greater demand. Baddeleyite is also found in gravel deposits in Ceylon; Matto Grosso, Brazil; and the Belgian Congo. In the United States, it has been reported in igneous rocks near Bozeman, Montana, and Davis Mountains, Texas.

Orangite (ThSiO_4). Orangite is a bright orange to orange-yellow variety of uranothorite, resulting from alteration of the uranium, as in the case of uranothorianite altering to thorogummite. It has been reported from Norway and Madagascar, but probably occurs in several other localities.

Huttonite (ThSiO_4). Huttonite is a mineral recently discovered in association with scheelite, cassiterite, uranothorite, zircon, ilmenite, and gold in the beach sands of South Westland, South Island, New Zealand, containing about 76 per cent ThO_2 , but no uranium. It has the same chemical composition as pure, unaltered thorite, but a different crystalline structure, similar to monazite. It occurs in very small, rounded, colorless to pale cream-colored grains somewhat heavier than thorite (specific gravity, 7). It fluoresces a dull white with pink tinge and may be distinguished from scheelite, which it closely resembles but which fluoresces blue, by means of an ultraviolet light.

Gadolinite [$2\text{BeO} \cdot \text{FeO} \cdot 2(\text{Y,Er})_2\text{O}_3 \cdot 2\text{SiO}_2$]. Gadolinite is a silicate of iron, beryllium, and the yttrium rare earths. Although rare, it is the primary source of gadolinium, a very rare member of the yttrium group of rare earths from which it takes its name. The rare earths are often replaced in part by thorium up to a maximum of about 2 per cent ThO_2 . Uranium may be present up to about 0.5 per cent U_3O_8 . Gadolinite contains from 6 per cent to 12 per cent beryllium oxide. It occurs in large, rough, massive crystals weighing up to 60 pounds; is black to deep green or brown when fresh but easily alters to yellowish-brown or brick red; has a greenish-gray, yellowish, or reddish-brown streak and a glassy luster becoming dull when altered. It has a hardness of 6.5-7 and a specific gravity of 4-4.5. Gadolinite occurs in pegmatites in association with fluorite, allanite, fergusonite, euxenite, samarskite, ilmenite, uraninite, cyrtolite, and thorite.

Small quantities have been produced commercially for gadolinium in southern Norway. It is also known to occur in Sweden; Llano County, Texas; Devils Head Mt., Colorado; Frontenac County, Ontario; Japan; Madagascar; Mozambique; and Namaqualand, South Africa.

Allanite (hydrous silicate of aluminum, calcium, iron, and cerium). Allanite is a black to dark brown hydrous silicate of aluminum, calcium, iron, and the rare earths, occurring most often in rough, massive crystals like gadolinite, but occasionally in tabular and slender needle-like crystals. It becomes green, gray, or yellow by alteration. It has a pale brown, gray, or greenish-brown streak when fresh and brown or yellow when altered; a glassy or resinous luster when fresh and greasy or earthy when altered; it breaks with an uneven fracture. Its hardness is 5.5-6 and its specific gravity is 2.7-4.2, becoming softer and lighter with alteration. Allanite occurs as a minor constituent in granite, pegmatites, and granite-like rocks; occasionally in volcanic rocks; and in certain limestone deposits near contacts with igneous rocks. It is commonly associated with magnetite, biotite, euxenite, betafite, zircon, fergusonite, thorite, and gadolinite. It is known in Greenland, Norway, Sweden, the U.S.S.R., Madagascar, Japan, Ontario, Quebec, and in a variety of localities in the United States, particularly in pegmatites in Amelia and Amherst Counties, Virginia; in Llano County, Texas; and in Wyoming.

Bastnäsite [$(\text{CeF})\text{CO}_3$]. Bastnäsite, sometimes called hamartite, is a rare earth fluorocarbonate which was originally a very rare mineral known to occur only in small quantities in Sweden; in gold placers in the Ural Mountains; in Madagascar; in the Belgian Congo; and near Pikes Peak, Colorado. However, it has recently been discovered in extensive vein-type deposits which may well supply a substantial part of the rare earth demand in the United States: with fluorite in the Gallinas Mountains, New Mexico, and with barite at Mountain Pass, southern California. Bastnäsite occurs in white or cream to reddish-brown tabular hexagonal crystals with diamond-like luster and a white streak. It is nearly transparent, has a hardness of 3-4.5 and a specific gravity of about 5. Bastnäsite contains up to 0.3 per cent ThO_2 , but is not now a commercial source of thorium. It also contains traces of uranium.

Appendix III—Mineral Identification

PHYSICAL PROPERTIES USED IN MINERAL IDENTIFICATION*

HARDNESS

By hardness is meant the resistance of a mineral to abrasion. Mohs' scale is generally used for the measurement of this property, utilizing the numbers 1 to 10 to designate the various degrees of hardness. A number of common articles greatly assist in this determination. These are included with the typical minerals used as the standards listed below.

1. **Talc**: easily scratched by the finger nail.

2. **Gypsum**: scratched with difficulty by the finger nail. Will not scratch a copper coin.

Finger nail: will scratch gypsum; will not scratch calcite. Hardness about 2.5.

3. **Calcite**: scratches copper and is scratched by copper. Not scratched by the finger nail.

Copper: scratches calcite; will not scratch fluorite. Hardness about 3.

4. **Fluorite**: does not scratch apatite or glass. Scratches copper.

5. **Apatite**: scratches glass with difficulty and is scratched by glass with difficulty.

Glass: scratches apatite but does not scratch feldspar. Hardness about 5-5.5.

6. **Feldspar** (orthoclase): scratches glass easily; scratched with difficulty by a knife blade.

Knife blade: will scratch feldspar; will not scratch quartz. Hardness 5.5-6.

7. **Quartz**: not scratched by a knife blade; scratched with difficulty by a file. **File**: will scratch quartz with difficulty; will not scratch topaz. Hardness about 7.

8. **Topaz**: will scratch quartz; will not scratch corundum; is scratched by corundum.

9. **Corundum**: will scratch topaz; will scratch silicon carbide with difficulty and is scratched by silicon carbide with difficulty. **Silicon carbide**: will scratch corundum; will not scratch diamond. Hardness about 9.

10. **Diamond**: not scratched by any known substance; will scratch all other substances.

The determination of the hardness is best made by scratching the sample with a knife blade to arrive at its approximate hardness and then determined exactly by means of the test minerals. With a little practice, hardness of 5 and below can usually be determined quite well with the knife blade only.

If a sample scratches feldspar and in turn is scratched by feldspar, they both have the same hardness, which is 6. If, however, it will not scratch feldspar but will scratch apatite and is not scratched by apatite, it has a hardness of 5.5.

In making the test, care must be taken to be sure the scratch is a distinct groove and not merely a chalk mark.

On some minerals the hardness of the various faces varies. Kyanite, for instance, has a hardness of 4-5 along the length of the crystal but 6-7 across it.

FUSIBILITY

The ease with which minerals melt or become plastic in a flame is designated by the numbers 1-7. All determinations are made with the mouth blowpipe, using no artificial air supply. Typical minerals and their approximate fusion points are given below.

1. **Stibnite**: fuses easily in the luminous flame, but in a closed tube and in a match or candle flame; about 525°C. (977°F.).

2. **Chalcopyrite**: fuses easily in the blowpipe flame but with difficulty in the luminous flame or closed tube; about 800°C. (1472°F.).

3. **Almandite**: fuses easily in the blowpipe flame but is not fused in the closed tube or luminous flame. Finest splinters only rounded on the point in the gas flame; about 1050°C. (1922°F.).

4. **Actinolite**: thin edges fuse easily in the blowpipe flame but larger masses are difficult to fuse; about 1200°C. (2192°F.).

5. **Orthoclase**: fuses on the edges with difficulty in the blowpipe flame; larger masses are not fused, only rounded; about 1300°C. (2372°F.).

* From O. C. Smith, *Identification and Qualitative Chemical Analysis of Minerals*, 2nd Edition, D. Van Nostrand Co., Inc., 1953.

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6. **Enstatite: Bronzite:** fused and rounded only on the thinnest edges and points of small pieces; about 1400°C. (2552°F.).

7. **Quartz:** infusible even on the thinnest edges and points of small pieces; over 1400°C. (2552°F.).

In using this scale, the hottest or oxidizing flame is used and the thinnest possible splinter of the mineral is tested. These should be held in the tip of the forceps or tweezers, so as to conduct away as little heat as possible. If the sample decrepitates so that splinters cannot be used, it should

example of the value of the streak is found with the mineral hematite, which may be steel gray, red or black in color but in which the streak is always red or brownish-red.

FRACTURE

The fracture is the type of surface obtained by breaking other than along a cleavage plane. Under this heading in the tables will be found the fracture characteristics in most cases, but as this is not reported in many minerals, other descriptive properties, such as brittle, granular, fibrous, etc., are also included in this column.

APPROXIMATE MELTING POINT OF VARIOUS METALS

| Metal | °C. | °F. | Metal | °C. | °F. |
|-----------|-----|--------|--|------|--------|
| Mercury | -39 | -38.2 | Gold | 1063 | 1945.6 |
| Tin | 232 | 449.6 | Copper | 1083 | 1981.4 |
| Bismuth | 271 | 519.8 | Nickel | 1455 | 2651.0 |
| Cadmium | 321 | 609.8 | Cobalt | 1480 | 2696.0 |
| Lead | 327 | 620.6 | Iron | 1535 | 2795.0 |
| Zinc | 419 | 786.2 | Platinum | 1774 | 3225.2 |
| Antimony | 630 | 1166.0 | Molybdenum | 2520 | 4568.0 |
| Magnesium | 650 | 1202.0 | Tungsten | 3370 | 6130.0 |
| Aluminum | 660 | 1220.0 | (Approximate limit of blowpipe flame, 1500°C.) | | |
| Silver | 961 | 1761.8 | | | |

be ground to a powder, mixed with a little water to form a paste, spread in a thin layer on charcoal and heated slowly then strongly until it forms a thin coherent mass that can be held in the forceps and tested in the oxidizing flame.

If a substance fuses easily in the blowpipe flame, but is infusible in the luminous flame or closed tube, it is said to have a fusibility of 3; if it is barely affected by the luminous flame it has a fusibility of 2.5.

STREAK

The powder of a mineral often has a color which is different from that of the solid, which aids greatly in its identification. This color is called the streak and may be obtained by noting the color of the ground mineral, by scratching the surface or by drawing the specimen over a piece of unglazed porcelain known as a **streak plate**. This leaves a streak or chalk-like mark of the mineral powder. An

TENACITY

The tenacity of a mineral is the resistance it offers to being broken, crushed, bent or torn apart. The usual designations for the types found in minerals are as follows:

Brittle: can be easily broken or powdered. Examples: galena and quartz.

Sectile: will cut with a knife, producing shavings. Examples: gypsum and chalcocite.

Malleable: when hammered, it clings together but gets thinner. Examples: gold, copper, etc.

Ductile: can be drawn out into wire. Examples: gold, copper, etc.

Flexible: thin layers can be bent without breaking and remain bent when released. Examples: some of the micas and foliated talc.

Elastic: thin layers can be bent without breaking, but resume their original shape when released. Examples: some of the micas.

APPENDIX III

USE OF THE FLAME IN MINERAL IDENTIFICATION*

THE FLAME AND ITS USE IN BLOWPIPING

An ordinary flame such as a candle or gas burner consists of three parts. Just above the wick or burner is the transparent zone "A," composed of gas or volatilized fuel that has not yet fired. Outside of this is zone "B," composed of burning gas. In the luminous flame it is rendered yellow by minute particles of incandescent carbon produced in the thermal decomposition of some of the hydrocarbons in the fuel. In the nonluminous flame this region is bluish as sufficient air is present to oxidize these compounds without the formation of particles of free carbon. Covering the entire outside is the faint bluish, hardly visible mantle, zone "C," composed of the products of complete combustion. See Fig. 9.

Flame Sources. Any convenient flame may be used for blowpiping, but for practical purposes only three sources will be considered here. They are the gas burner, alcohol lamp, and the candle.

For use in a permanent laboratory,

domestic gas and a Bunsen burner (Fig. 10) equipped with a blowpipe tip (Fig. 9(d)) is most convenient. With this arrangement excellent oxidizing and reducing flames can be produced and a large amount of heat is available when desired.

For field use or where gas is not available, the alcohol or spirit lamp (Fig. 11) or candle may be used. The alcohol lamp does not produce a very good reducing flame but otherwise is quite satisfactory. The candle does give a good reducing flame but has the objection of not supplying much heat and tends to melt down quickly. Plumber's candles are probably best for general use as they are made from a higher melting point wax than the ordinary candle.

A **blowpipe** (Fig. 12) is a tube, usually of brass, so arranged that a fine jet of air may be delivered from the mouth of the operator, at right angles to his line of vision, into or through a flame, thus directing and controlling the amount of heat and type of flame applied.

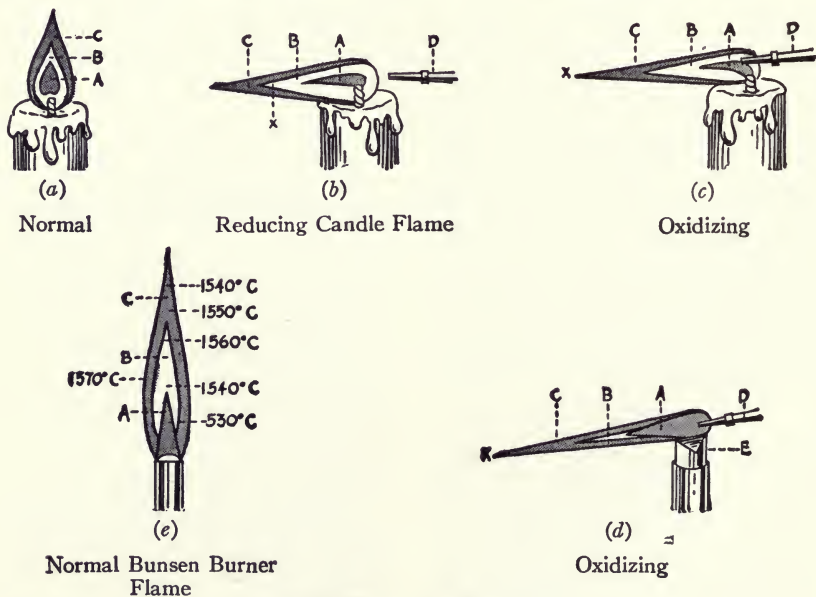


FIG. 9. Blow Pipe Flames.

* From O. C. Smith, *Identification and Qualitative Chemical Analysis of Minerals*, 2nd Edition, D. Van Nostrand Co., Inc., 1953.



FIG. 10. Bunsen Burner.

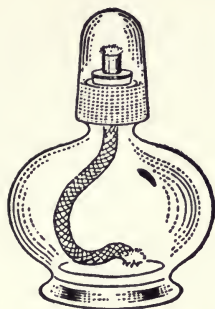


FIG. 11. Alcohol Lamp.

Learning the proper use of the blowpipe is somewhat difficult; a novice is inclined to blow with his lungs, which is incorrect. Good blowpiping can be accomplished only after the proper method has been learned. The success of blowpiping as a means of making qualitative tests depends on its proper manipulation, as it is necessary that the operator be able to produce a strong, steady oxidizing or reducing flame for an indefinite period. Considerable practice may be required before this can be accomplished.

The blowpipe is held in any convenient manner, with the mouth piece held firmly between the lips or firmly pressed against them. The cheeks are filled with air and the passage between the throat and mouth is closed with the tongue in the same manner as one puffs out one's cheeks. If this is done the cheeks will remain full of air and breathing through the nose can be carried on without in any way disturbing the air held in the mouth. This accomplished, the air in the mouth is expelled by the cheek muscles through the blowpipe. As the air is depleted, a fresh supply is taken in through the nose without interrupting the flow through the blowpipe. In this way a steady flame is produced and breathing is carried on normally through the nostrils.

The production of the oxidizing flame by the candle and Bunsen burner is illustrated in *c* and *e* of Fig. 9. The Bunsen burner has slipped over it a blowpipe tip ("E")



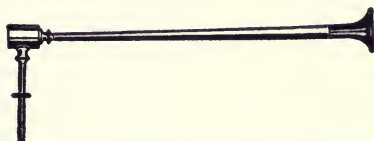
SIMPLE BLOWPIPE



BULB TYPE BLOWPIPE



BLACK'S BLOWPIPE



PLATTNER'S BLOWPIPE

FIG. 12. Types of Mouth Blowpipes.

which gives a flat flame and provides a support for the blowpipe.

In producing the **oxidizing flame** (O.F.), the tip of the blowpipe is inserted about $\frac{1}{8}$ " into the flame (Fig. 9 (c) and (d)). A steady current of air will elongate the flame into a narrow cone with a point almost as definite as a needle, and the luminous part will disappear if sufficient air is used. An oxidizable substance, if held at the point "X" or even further in toward the tip of the cone "B," will be rapidly oxidized. Flame tests are made by holding the material being tested at this place. Since the flame of the Bunsen burner just above the tip of the inner cone "B" ((e) of Fig. 9) is the hottest, fusions can be made here also.

APPENDIX III

In general, **oxidation** proceeds best when the substance is kept at a dull red heat. The blue cone must be kept free from straggling yellow rays of the reducing flame. If the analysis is carried out on charcoal, the blast of air should not be too strong, as much of the coal will be converted to carbon monoxide, which has a strong reducing action and will tend to retard the oxidation. The oxidizing flame requires a steady current of air, so as to keep the blue cone constantly of the same length. Practice in producing this flame may be carried out by melting a little molybdic acid with some borax, on a platinum wire, about $\frac{1}{16}$ " from the point to the cone. In the pure oxidizing flame, a clear yellow glass is formed; but as soon as the reducing flame touches it, the color of the bead changes to brown, which finally, after a little blowing, becomes quite dark and loses its transparency. The cause of this is that the molybdic acid is very easily reduced to a lower degree of oxidation. The pure oxidizing flame will again convert this dark bead into a clear one, and this conversion is a good test of the progress of the student in the use of the blowpipe. An easily oxidizable substance may be separated from one which is more resistant by careful use of the oxidizing flame.

The **reducing flame** (R.F.) is illustrated in (b) of Fig. 9. This flame is produced by holding the tip of the blowpipe *outside* of the flame a short distance above the wick or burner top. A jet of air blows the entire flame into a horizontal cone, but not to a fine point as in the oxidizing flame. The air used is not sufficient to destroy the luminosity, but does oxidize much of the free carbon, thus giving a higher temperature. A reducible substance held at "X" in the yellow tip of the cone "B" will be rapidly deoxidized or reduced.

If the oxide of a metal is brought into the luminous part of the flame produced as above, so that the flame envelops the substance completely, the access of air is prevented. The partially consumed gases now have a strong affinity for oxygen, under the influence of the intense heat of that part of the flame. The substance is thus deprived of a part or all of its oxygen and becomes reduced according to the relative affinity which the substance has for oxygen. If the reduction of a substance is attempted on platinum, by fusion with a flux, or if the

oxide is difficult to reduce, the reduction will be completely effected only in the luminous flame. But if a substance be reduced on charcoal, the reduction will take place in the blue part of the flame, as long as the excess of air is cut off. However, it is the luminous part of the flame which possesses the greatest reducing power.

For the purpose of practice, the student may fuse the oxide of manganese with borax on a platinum wire in the oxidizing flame. A violet-red glass should be obtained. If too much of the oxide is used, an opaque glass of a dark color will result. By submitting this glass to a reducing flame, it will become colorless in correspondence to the perfection with which the flame is produced. Also a piece of metallic tin may be fused on charcoal and kept in this state for a considerable time, while it presents the appearance of bright metal on the surface. This will require dexterity of the operator, for if the oxidizing flame should chance to touch the bright metal for only a moment, it will be coated with an infusible oxide.

Many of the elements give very characteristic reactions when subjected to different treatments under the blowpipe.

BEAD TESTS

Borax and Salt of Phosphorus (Microcosmic Salt) have the property of absorbing the oxides of metals, yielding, in many cases, pronounced colors. This is made use of in the bead tests, which for a number of the elements are characteristic and are a useful aid in identification and analysis of minerals.

The test is carried out with a small loop, about the size of a pinhead, at the end of a platinum wire which has been sealed in a 3"-4" piece of glass rod or tubing by heating the glass till soft, then inserting the platinum wire. The loop is easily made by bending the end of the wire around the tip of a lead pencil.

In making the bead, the loop is touched while hot to the borax or salt of phosphorus powder, which causes some of it to adhere. On heating, this will form into a small ball or bead. If the bead is not large enough, the hot bead is touched to the borax or salt of phosphorus again and reheated. The operation is repeated until the bead is of the desired size. Making the borax bead is quite simple, but on heating the microcosmic salt to form the salt of phosphorus bead

MINERAL IDENTIFICATION

BORAX BEAD TESTS

| | OXIDIZING FLAME | | REDUCING FLAME | |
|-------------------|-------------------|---|--------------------------|---------------------------------------|
| | Hot | Cold | Hot | Cold |
| Antimony | Pale yellow. | Colorless to white. | Pale yellow. | Colorless. |
| Bismuth | Pale yellow. | Colorless to white. | Gray. | Gray. |
| Cadmium | Pale yellow. | Colorless to white. | Pale yellow. | Colorless. |
| Cerium | Yellow. | Greenish yellow. | Colorless. | Colorless. |
| Chromium | Yellow. | Green. | Green. | Green. |
| Cobalt | Blue. | Blue. | Blue. | Blue. |
| Copper | Green. | Blue. | Colorless to green. | Brownish, opaque red with much oxide. |
| Didymium | Pale rose. | Pale rose. | Pale rose. | Pale rose. |
| Iron | Yellow to orange. | Greenish to brown. | Bottle-green. | Pale bottle-green. |
| Lead | Pale yellow. | Colorless to white. | Pale yellow. | Colorless. |
| Manganese | Violet. | Brownish to reddish violet. | Colorless. | Colorless. |
| Molybdenum | Pale yellow. | Colorless to white. | Brown. | Brown to black and opaque. |
| Nickel | Violet | Reddish brown. | Opaque gray. | Opaque gray. |
| Titanium | Pale yellow. | Colorless to white. | Grayish or yellowish. | Brownish. |
| Tungsten | Pale yellow. | Colorless to white. | Yellow. | Brownish. |
| Uranium | Yellow to orange. | Yellow to brown. Can be flamed enamel-yellow. | Pale green. | Green. Can be flamed black. |
| Vanadium | Yellow. | Green. | Brownish to dirty green. | Yellow to green. |

APPENDIX III

SALT OF PHOSPHORUS BEADS

| | OXIDIZING FLAME | | REDUCING FLAME | |
|-------------------|--------------------------|-------------------------------|-----------------------------------|--|
| | Hot | Cold | Hot | Cold |
| Antimony | Pale yellow. | Colorless. | Gray. | Gray. |
| Bismuth | Pale yellow. | Colorless. | Gray. | Gray. |
| Cadmium | Pale yellow. | Colorless. | Pale yellow. | Colorless. |
| Cerium | Brownish yellow. | Light yellow. | Light yellow, opaque. | Colorless, opaque. |
| Chromium | Reddish to dirty green. | Yellowish green to green. | Red to dirty green. | Green. If not completely reduced it is brown to red. |
| Cobalt | Blue. | Blue. | Blue. | Blue. |
| Columbium | Pale yellow. | Colorless. | Brown. | Red-brown. |
| Copper | Dark green. | Greenish blue. | Brownish green. | Opaque red. |
| Didymium | Pale rose. | Pale rose. | Pale rose. | Pale rose. |
| Iron | Yellow to brownish red. | Brownish yellow. | Red or yellow to greenish yellow. | Pale violet. |
| Lead | Pale yellow. | Colorless. | Gray. | Gray. |
| Manganese | Grayish violet. | Violet. | Colorless. | Colorless. |
| Molybdenum | Yellowish green. | Colorless. | Dirty green. | Yellowish green. |
| Nickel | Reddish to brownish red. | Yellow to brownish. | Reddish to brownish red. | Yellow to brownish. |
| Silica | Insoluble skeleton. | Insoluble skeleton. | Insoluble skeleton. | Insoluble skeleton. |
| Tantalum | Pale yellow. | Colorless. | Pale yellow. | Colorless. |
| Titanium | Pale yellow. | Colorless. | Yellow. | Delicate violet. |
| Tungsten | Pale yellow. | Colorless. | Greenish to dirty blue. | Greenish blue. |
| Uranium | Yellow. | Yellowish green to colorless. | Pale dirty green. | Green. |
| Vanadium | Yellow. | Greenish yellow. | Brown to dirty green. | Green. |

BORAX BEADS



Molybdenum
R. F.



Tungsten
R. F.



Titanium
R. F.



Chromium
O. F.



Chromium
R. F.



Cerium
O. F.



Vanadium
O. F.



Vanadium
R. F.



Iron
O. F.



Iron
R. F.



Uranium
O. F.



Uranium
R. F.



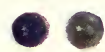
Copper
O. F.



Copper
R. F.



Nickel
O. F.



Cobalt
O. F.



Cobalt
R. F.



Manganese
O. F.

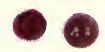


Didymium
O. F.



Didymium
R. F.

SALT OF PHOSPHORUS BEADS



Columbium
R. F.



Tungsten
R. F.



Uranium
R. F.



Iron
O. F.



Iron
R. F.



Molybdenum
R. F.



Vanadium
O. F.



Vanadium
R. F.



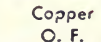
Nickel
O. F.



Nickel
R. F.



Titanium
R. F.



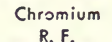
Copper
O. F.



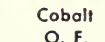
Copper
R. F.



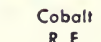
Chromium
O. F.



Chromium
R. F.



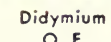
Cobalt
O. F.



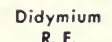
Cobalt
R. F.



Manganese
O. F.



Didymium
O. F.



Didymium
R. F.

MINERAL IDENTIFICATION

there is quite an effervescence so that at first it froths badly and is likely to drop off the wire. However, if heated gently and carefully at first, the foaming soon ceases and the bead remains on the wire. The heating of the microcosmic salt ($\text{HNaNH}_2\text{PO}_4 \cdot 4\text{H}_2\text{O}$) decomposes it with the formation of sodium metaphosphate (NaPO_3). If this latter substance is used in the formation of the salt of phosphorus bead, no difficulty from frothing is encountered.

The bead must be clear and colorless both hot and cold; if it is not, the bead is heated red hot and then thrown off the wire by striking the hand holding the wire on the other hand. Another bead is then made, and, if necessary, another one, until a colorless one is obtained. The color is due to some foreign substance which is removed by this procedure, thus cleaning the loop.

In making bead tests the clear, colorless bead is heated and, while hot, is touched to the powder of the substance to be tested. A small amount of the substance adheres and, on reheating, is absorbed in the bead. For absorption, the powder tested should consist of oxides; however, if the bead is heated in the oxidizing flame, most compounds will be changed to oxides, and yield the desired test result (color of bead).

In examining the bead, the color should be noted while the bead is still hot after removal from the flame, while it is cooling, and after it is cold (cold) by transmitted light. Opaque beads, of course, must be viewed by reflected light. The colors by artificial light are usually different from those by sunlight, so that daylight should be used wherever possible. It is well to heat

the bead in the O.F. a second time to be sure the reactions are complete; then it is retreated with the reducing flame and carefully examined both hot and cold after each heating.

If a bead does not develop sufficient color, a little more of the substance being tested is added, but care must be taken that too much is not used or the bead will become so dark in color that light will not pass through it or it is unable to absorb all of the solid.

FLUORESCENT BEADS

Borax and Salt of Phosphorus Beads.

The only minerals which respond to the short-wave ultraviolet light are the uranium, O.F. (greenish) and copper, R.F. (pinkish) of the borax beads and the uranium, R.F. (greenish), copper, R.F. (reddish) and tungsten, R.F. (pinkish) of the phosphorus beads.

Sodium Fluoride and Lithium Fluoride Beads. These are made in the same manner as the borax and phosphorus beads using the O.F. It is not necessary to use platinum for these beads, as iron wire will serve equally well. No distinctive color is imparted to the fluoride beads by the elements. However, a pronounced response to ultraviolet light is obtained with certain elements present and, in the case of uranium, this constitutes a quite sensitive field and laboratory test. The presence of thorium and the rare earths interfere with the uranium test. The beads, subjected to both the short wave (2450 Angstrom units) and long wave (3660 Angstrom units) Mineralight give the response listed below.

SODIUM FLUORIDE

| <i>Element</i> | <i>Short wave</i> | <i>Long wave</i> |
|------------------------|------------------------|------------------|
| Bismuth | Blue-white | Yellow |
| Columbium | Blue-white | none |
| Titanium | Light green | none |
| Tungsten | Light bluish yellow | none |
| Uranium | Brilliant lemon-yellow | Bright yellow |

LITHIUM FLUORIDE

| <i>Element</i> | <i>Short wave</i> | <i>Long wave</i> |
|------------------------|-------------------|------------------|
| Bismuth | Orange | Dark orange |
| Columbium | none | none |
| Titanium | Dark green | none |
| Tungsten | Light blue | none |
| Uranium | Brilliant blue | Blue-green |

APPENDIX III

TABLE OF ABBREVIATIONS OF CHEMICAL ELEMENTS

| | | | |
|----------------|----------------|-------------------|---------------|
| A —Argon | F —Fluorine | Na —Sodium | S —Sulfur |
| Ac —Actinium | Fe —Iron | Nb —Columbium | Sb —Antimony |
| Ag —Silver | Ga —Gallium | (Niobium) | Sc —Scandium |
| Al —Aluminum | Gd —Gadolinium | Nd —Neodymium | Se —Selenium |
| As —Arsenic | Ge —Germanium | Ne —Neon | Si —Silicon |
| Au —Gold | H —Hydrogen | Ni —Nickel | Sm —Samarium |
| B —Boron | He —Helium | O —Oxygen | Sn —Tin |
| Ba —Barium | Hf —Hafnium | Os —Osmium | Sr —Strontium |
| Be —Beryllium | Hg —Mercury | P —Phosphorus | Ta —Tantalum |
| Bi —Bismuth | Ho —Holmium | Pa —Protoactinium | Tb —Terbium |
| Br —Bromine | I —Iodine | Pb —Lead | Te —Tellurium |
| C —Carbon | In —Indium | Pd —Palladium | Th —Thorium |
| Ca —Calcium | Ir —Iridium | Pm —Promethium | Ti —Titanium |
| Cd —Cadmium | K —Potassium | Po —Polonium | Tl —Thallium |
| Ce —Cerium | Kr —Krypton | Pr —Praseodymium | Tm —Thulium |
| Cl —Chlorine | La —Lanthanum | Pt —Platinum | U —Uranium |
| Co —Cobalt | Li —Lithium | Pu —Plutonium | V —Vanadium |
| Cr —Chromium | Lu —Lutecium | Ra —Radium | W —Tungsten |
| Cs —Cesium | Ma —Masurium | Rb —Rubidium | Xe —Xenon |
| Cu —Copper | Mg —Magnesium | Re —Rhenium | Y —Yttrium |
| Dy —Dysprosium | Mn —Manganese | Rh —Rhodium | Yb —Ytterbium |
| Er —Erbium | Mo —Molybdenum | Rn —Radon | Zn —Zinc |
| Eu —Europium | N —Nitrogen | Ru —Ruthenium | Zr —Zirconium |

RADIOACTIVE MINERALS IDENTIFICATION TABLE

The Radioactive Minerals Identification Table comprises the better known uranium and thorium minerals—minerals that will cause the counter to react. All of the uranium minerals in this table will give positive fluoride bead tests for uranium as will those

thorium minerals so indicated. The minerals are arranged in groups by color and cross-referenced if they occur in more than one color. The minerals in each group are arranged in approximate decreasing order of both hardness and specific gravity.

RADIOACTIVE MINERALS IDENTIFICATION TABLE

GROUP 1—BLACK MINERALS

| | Hard- ness | Approx. Specific Gravity | Name | Chemical Composition | Luster | Fluores- cence |
|----|---------------------|--------------------------------|---|---|-------------------------------|-------------------|
| 1. | (Quartz = 7) 5-7 | 9 $\frac{1}{2}$ | Thorianite (also brownish, grayish) | Thorium and uranium oxide (50-90% ThO ₂ ; 0-33% U ₃ O ₈) | Sub-metallic, dull, or greasy | None |
| 2. | 5-7 | 9 $\frac{1}{2}$ | Urano-thorianite (also brownish, grayish) | Uranium thorium oxide (85% or less ThO ₂ ; 15% or more U ₃ O ₈) | Sub-metallic or dull | None |
| 3. | 5-6 | 8-10.5 | Uraninite (also grayish, greenish, brownish) | Mixture UO ₂ and UO ₃ with varying amounts of lead, rare earths and thorium. (50-85% U ₃ O ₈) | Glassy, dull, sub-metallic | None |
| 4. | 5-6 (variable) | 6-9 | Pitchblende | Same as uraninite. Less than 1.5% rare earths and thorium. (50-80% U ₃ O ₈) | Pitch-like, dull | None |
| 5. | 6.5 | 5.5-6 | Baddeleyite | See Brown Minerals (Group 2) | | |
| 6. | 6-7 | 4-4.5 | Gadolinite | See Green Minerals (Group 5) | | |
| 7. | 5.5-6.5 | 4-6 (variable) | Euxenite-Polyorase (also very dark brown with reddish cast) | Oxides or columbates and titanates of the yttrium group rare earths; variable amounts of uranium, thorium, and cerium. (Up to 20% U ₃ O ₈) | Glassy when fresh | None |
| 8. | 5.5-6 | 4.5-5 | Zirkelite (also brownish black) | Oxide of calcium, iron, thorium, zirconium and titanium; minor uranium. (Up to 20% ThO ₂ ; up to 14% U ₃ O ₈) | Submetallic to resinous | None |

RADIOACTIVE MINERALS IDENTIFICATION TABLE

GROUP 1—BLACK MINERALS

| Fracture | Streak | Habit | Mode of Occurrence | Remarks |
|------------------------------|---------------------------|---|---|---|
| Uneven to conchoidal | Black, gray, greenish | Cubes | Placers; less commonly in pegmatites and granite. | Sometimes has a bronze tarnish. Soluble in HNO_3 and H_2SO_4 . |
| Conchoidal | Black, gray, greenish | Cubes | de | Positive fluoride bead for uranium. More commonly altered than thorianite. |
| Uneven, sub-conchoidal | Brownish black to grayish | Octahedral, cubic, massive | Pegmatites and veins; small amounts in bedded and disseminated deposits. | In thin slivers or powdered always black, never brownish or reddish like the refractory pegmatite minerals. Also more radioactive. Same crystal form as thorianite. |
| Uneven, sub-conchoidal | Brownish black to grayish | Botryoidal, banded, massive; also fine-grained powder mixed with other minerals especially copper sulfides and hydrocarbons | In veins and bedded deposits with other metallic minerals particularly sulfides and hydrocarbons. | Pitchblende is the name applied to the variety of uraninite occurring without obvious crystal form in veins associated with base-metal sulfides and low in thorium. |
| | | | | |
| | | | | |
| Conchoidal | Pale yellow to brown | Massive; less commonly staurolite prismatic crystals | Pegmatites; less commonly placers | In thin slivers or powdered, brownish or reddish, not black or green like uraninite or pitchblende. Resembles samarskite. May contain trace of beryllium. |
| Conchoidal to sub-conchoidal | Chocolate brown | Tabular or prismatic crystals | Basic igneous rocks; placers | Usually associated with other zirconium minerals. High uranium variety will give positive fluoride bead test for uranium. Non-magnetic. |

RADIOACTIVE MINERALS IDENTIFICATION TABLE

GROUP 1—BLACK MINERALS

| | Hard- ness | Approx. Specific Gravity | Name | Chemical Composition | Luster | Fluores- cence |
|-----|--------------------------------|--------------------------------|--|---|---|-------------------|
| 9. | 5-6 | 4-6 | Samarskite (also very dark brown with reddish cast) | Columbate and tantalate of the yttrium group rare earths; variable amounts of uranium, thorium, calcium, and iron. (Up to 21% U_3O_8) | Glassy when fresh | None |
| 10. | 5-6 | 4-6 | Pyrochlore- microlite | See Brown Minerals (Group 2) | | |
| 11. | 5-6 | 4-6 | Fergusonite- formanite | See Brown Minerals (Group 2) | | |
| 12. | 5-6 | 4.5 (vari- able) | Davidite (also dark brown) | Oxide of iron and titanium (7-10% U_3O_8) | Glassy, sub- metallic | None |
| 13. | 5.5-6 (Knife blade = 5.5-6) | 3-4 | Allanite | See Brown Minerals (Group 2) | | |
| 14. | 4-5 | 4.5-5.5 | Brannerite (usually altered to brown or yellow-brown) | Oxide of uranium and titanium with minor rare earths, calcium, thorium and iron. (Up to 40% U_3O_8 and 14% ThO_2) | Dull, earthy or greasy to resinous when altered; glassy when fresh | None |
| 15. | 4.5-5 | 4-6 | Thorite (often greenish; some- times reddish- brown and orange) | Thorium silicate with minor uranium. 35-80% ThO_2 ; 0-22% U_3O_8 . (Uranothorite when uranium exceeds 5% U_3O_8) | Glassy when fresh; dull to greasy when altered. | None |
| 16. | 4-5.5 | 4-5 | Betafite (also dark greenish brown) | Oxide of columbium, titanium, and uranium with minor calcium, iron rare earths and titanium. (15-27% U_3O_8) | Glassy to sub- metallic | None |
| 17. | 3.5-4 (copper = 3) | 1.75-2 | Thucholite (also brownish black) | Hydrocarbon and uranium. (2-8% U_3O_8) | Dull, pitchlike | None |
| 18. | Soft | | Rauvite (also purple) | Hydrous calcium, uranium, vanadate. Up to 25% U_3O_8 . | Dull | None |

RADIOACTIVE MINERALS IDENTIFICATION TABLE

GROUP 1—BLACK MINERALS

| Fracture | Streak | Habit | Mode of Occurrence | Remarks |
|--------------------------|--|--|--|---|
| Conchoidal | Dark brown to black when fresh | Massive; rough prismatic crystals | Pegmatites; less commonly placers | In thin slivers or powdered, brownish or reddish, not black or green like uraninite or pitchblende. Resembles euxenite. May contain trace of beryllium. |
| | | | | |
| | | | | |
| Sub-conchoidal to uneven | Dark Brown | Massive; occasionally large crystals. | High temperature veins. | Intimately associated with ilmenite. Usually moderately magnetic with hard magnet. Often has greenish-yellow, tyuyamunite or carnotite stains when exposed to weathering. |
| | | | | |
| Conchoidal | Yellow-brown when altered; dark greenish brown when fresh. | Prismatic crystals; rounded masses or grains | Pegmatites, granite, placers | Decomposed by hot concentrated H_2SO_4 |
| Conchoidal | Variable | Small square, prismatic crystals with pyramidal terminations; sometimes massive. | Placers; minor amounts in granite, pegmatites. | Same crystal form as zircon. Massive varieties usually uranothorite. May contain trace of beryllium. Infusible. |
| Conchoidal | Dark brown to yellow-brown | Octahedral crystals | Pegmatites; occasionally in placers. | Commonly altered to brown or yellow-green. Forms black slag in blowpipe flame. |
| Conchoidal | - - - - | Coal-like; irregular nodules | Pegmatites, veins, asphaltic sedimentary rocks. | Will burn. Possibly a mixture of hydrocarbon and uraninite. |
| Brittle | Light brown, slightly yellowish | Powdery masses; botryoidal; massive. | Associated with carnotite-resocelite ores in sandstones. | - - - - |

RADIOACTIVE MINERALS IDENTIFICATION TABLE

GROUP 2—BROWN MINERALS

| | Hard- ness | Approx. Specific Gravity | Name | Chemical Composition | Luster | Fluores- cence |
|-----|---------------------|--------------------------------|---|--|--------------------|-------------------|
| 1. | (Quartz = 7) 5-7 | 9 $\frac{1}{2}$ | Thorianite | See Black Minerals (Group 1) | | |
| 2. | 5-7 | 9 $\frac{1}{2}$ | Urano-thorianite | See Black Minerals (Group 1) | | |
| 3. | 5-6 | 8-10.5 | Uraninite | See Black Minerals (Group 1) | | |
| 4. | 6.5 | 5.4-6 | Baddeleyite (also yellow or black) | Zirconium oxide. ($^{232}\text{U}_3\text{O}_8$ or ThO_2) | Sub- metallic | None |
| 5. | 6.5-7 | 4-4.5 | Gadolinite | See Green Minerals (Group 5) | | |
| 6. | 5.5-6 | 4.5-5 | Zirkelite | See Black Minerals (Group 1) | | |
| 7. | 5.5-6.5 | 4-6 (vari- able) | Fergusonite- formanite (Dark brown to black with reddish cast; occasionally yellow brown) | Columbates and tantalates of yttrium rare earths with variable amounts of uranium, thorium, calcium, iron and titanium. (Up to 8% U_3O_8) | Glassy | None |
| 8. | 5.5-6.5 | 4-6 | Euxenite-polyrase | See Black Minerals (Group 1) | | |
| 9. | 5-6 | 4-6 | Samarskite | See Black Minerals (Group 1) | | |
| 10. | 5-6 | 4-6 (vari- able) | Pyrochlore-microlite (also colorless, yellow, red, green, or black) | Complex oxides of columbium, tantalum, sodium, calcium, and fluorine. (Up to 15% U_3O_8). | Glassy or resinous | None |
| 11. | ? | 6.2 | Parsonsite | $2\text{PbO} \cdot \text{UO}_3 \cdot \text{P}_2\text{O}_5 \cdot \text{H}_2\text{O}$ (30% U_3O_8) | Greasy | None |

RADIOACTIVE MINERALS IDENTIFICATION TABLE

GROUP 2—BROWN MINERALS

| Fracture | Streak | Habit | Mode of Occurrence | Remarks |
|---|---------------------------------------|---|--|---|
| | | | | |
| | | | | |
| Uneven | Pale brown or yellow | Tabular crystals; massive | With zirkelite in basic igneous rocks and placers | In blowpipe flame, glows, turns white and is nearly infusible. Insoluble in Hcl. |
| | | | | |
| | | | | |
| Conchoidal to uneven | Pale yellow to brown or greenish gray | Rough prismatic crystals | Pegmatites and placers | In thin slivers or powdered, brownish or reddish, not black or green like pitchblende or uraninite. Usually coated with buff to pinkish earthy clay-like material. May contain trace of beryllium. Infusible. Decomposed by H_2SO_4 . |
| | | | | |
| | | | | |
| Conchoidal, uneven, splintery, brittle. | Colorless, pale yellow, brownish | Octahedral crystals; small grains; irregular masses embedded in other minerals. | Pegmatites. Often associated with lithium and fluorine minerals. | Darker colors pyrochlore; lighter colors microcline. Often easily scratched with a knife due to alteration. May contain trace of beryllium. Infusible. |
| - - - - | Pale brown | Minute tabular crystals or earthy masses. | Alteration product of uraninite | Yields water when heated in closed tube. Soluble in Hcl. |

RADIOACTIVE MINERALS IDENTIFICATION TABLE

GROUP 2—BROWN MINERALS

| | Hard- ness | Approx. Specific Gravity | Name | Chemical Composition | Luster | Fluores- cence |
|-----|-----------------------------------|--------------------------------|--|---|--|--------------------------|
| 12. | 5-6 | 4.5 | Davidite | See Black Minerals (Group 1) | | |
| 13. | 5.5-6 (Knife blade = 5.5-6) | 3-4 | Allanite (orthite) (dark brown to black; alters to green, gray, or yellow) | Hydrous silicate of aluminum, calcium, iron and the cerium group rare earths. (Up to 5% ThO ₂ ; up to 1% U ₃ O ₈) | Sub- metallic, glassy, or resinous when fresh; dull, greasy or earthy when altered | None |
| 14. | 5-5.5 (Glass = 5-5.5) | 4.6-5.3 | Monazite | See Yellow Minerals (Group 3) | | |
| 15. | 4.5-5 | 4-6 | Thorite | See Black Minerals (Group 1) | | |
| 16. | 4-5.5 | 4-5 | Betafite | See Black Minerals (Group 1) | | |
| 17. | 4-6 | variable | Gummite | See Orange Minerals (Group 4) | | |
| 18. | 4-5 | 4.5-5.5 | Brammerite | See Black Minerals (Group 1) | | |
| 19. | 4-5 | 4.5 | Xenotime | See Yellow Minerals (Group 3) | | |
| 20. | 3-4 | 6 | Fourmarierite | See Red Minerals (Group 6) | | |
| 21. | 3-6 | 3.6-4.1 | Cyrtolite (dark reddish to gray- ish brown; oc- casionaly colorless to pale yellow) | Zirconium silicate with minor rare earths, uranium, and thorium. (Up to 5% ThO ₂ and 3% U ₃ O ₈) | Glassy to dull or sub- resinous | Some- times yellow |
| 22. | 3-6 (Copper = 3) | 3.6-4.1 | Naegite | See Green Minerals (Group 5) | | |
| 23. | Soft | | Uvanite (brownish yellow) | Hydrous uranium vanadate. (Up to 40% U ₃ O ₈) | Pearly | None |

RADIOACTIVE MINERALS IDENTIFICATION TABLE

GROUP 2—BROWN MINERALS

| Fracture | Streak | Habit | Mode of Occurrence | Remarks |
|--------------------------|----------------------------------|---|---------------------------------------|--|
| Uneven to sub-conchoidal | Pale brown, grayish, or greenish | Tabular or long slender crystals; massive | Pegmatites; small amounts in granite. | Alters easily to various colors with decrease in hardness and specific gravity. May contain trace of beryllium. Yields water when heated in closed tube. |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| Conchoidal | Pale brown or yellow | Long, square, prismatic crystals with pyramidal terminations. | Granite, gneiss, schist; placers | A variety of zircon. |
| | | | | |
| - - - - | Brownish yellow | Fine granular earthy masses or crystals | Uranium-bearing asphaltic sandstones. | A rare mineral associated with other vanadium and secondary uranium minerals. Soluble in $(\text{NH}_4)_2\text{CO}_3$. |

RADIOACTIVE MINERALS IDENTIFICATION TABLE

GROUP 3—YELLOW MINERALS

| | Hard- ness | Approx. Specific Gravity | Name | Chemical Composition | Luster | Fluores- cence |
|-----|---------------------------------|--------------------------------|--|---|-----------------------|-------------------|
| 1. | (Quartz = 7) 6.5 | 5.4-6 | Baddeleyite | See Brown Minerals (Group 2) | | |
| 2. | 6.5-7 | 4-4.5 | Gadolinite | See Green Minerals (Group 5) | | |
| 3. | 5.5-6.5 | 4-6 | Fergusonite- fermanite | See Brown Minerals (Group 2) | | |
| 4. | 5.5-6 | 3-4 | Allanite | See Brown Minerals (Group 2) | | |
| 5. | 5-6 (Knife blade = 5.5-6) | 4-6 | Pyrochlore- microlite | See Brown Minerals (Group 2) | | |
| 6. | 5-5.5 (Glass = 5-5.5) | 4.6-5.3 | Monazite (also brown) | Rare earths phosphate. (Up to 15% ThO ₂ and 1% U ₃ O ₈) | Resinous | None |
| 7. | 4.5-5 | 4-6 | Thorite (orangeite) | See Black Minerals (Group 1) | | |
| 8. | 4-5 | 6 | Kasolite (slightly brownish) | PbO.UO ₃ .SiO ₂ .H ₂ O (45% U ₃ O ₈) | Resinous to greasy | None |
| 9. | 4-5 | 4.5 | Xenotime (also varying shades of pink, brown and green) | Rare earths phosphate. (Up to 5% ThO ₂ and 4% U ₃ O ₈) | Resinous | None |
| 10. | 4-6 | variable | Guzmite | See Orange Minerals (Group 4) | | |
| 11. | 4-5 | 4.5-5.5 | Brannerite | See Black Minerals (Group 1) | | |
| 12. | 3-6 | 3.6-4.1 | Cyrtolite | See Brown Minerals (Group 2) | | |
| 13. | 3-4 (Copper = 3) | 4-6 | Soddyite | 5UO ₃ .2SiO ₂ .6H ₂ O (80% U ₃ O ₈) | Dull, pearly | ? |

RADIOACTIVE MINERALS IDENTIFICATION TABLE

GROUP 3—YELLOW MINERALS

| Fracture | Streak | Habit | Mode of Occurrence | Remarks |
|----------------------|---|--|---|--|
| | | | | |
| | | | | |
| | | | | |
| Conchoidal | Colorless to pale brown or yellow. | Flattened crystals; rounded grains. | Placers; pegmaties. | Infusible. Partly soluble in HCl. |
| | | | | |
| - - - - | Pale yellow | Minute tabular crystals in radiating bunches; compact, granular. | A rare alteration product. | Gelatinizes in HCl. |
| Uneven and splintery | Colorless to pale yellow, brown, red or greenish gray | Prismatic crystals with pyramidal termination; rounded grains. | Placers; pegmatites. | Very similar in appearance and occurrence to monazite. Infusible. Insoluble in HCl. |
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| | | | | |
| - - - - | Pale yellow | Minute prismatic and pyramidal crystals. | Associated with other secondary uranium minerals. | A rare mineral. When heated in closed tube, blackens and releases water and oxygen. Infusible. Gelatinizes in HCl. |

RADIOACTIVE MINERALS IDENTIFICATION TABLE

GROUP 3—YELLOW MINERALS

| | Hard- ness | Approx. Specific Gravity | Name | Chemical Composition | Luster | Fluores- cence |
|-----|----------------------------|--------------------------------|--|---|---------------------------------|--------------------------|
| 14. | 2-3 | 5-5.7 | Becquerelite (also brownish yellow) | $2\text{UO}_3 \cdot 3\text{H}_2\text{O}$ (80% U_3O_8) | Diamond- like to resinous | None |
| 15. | 2-3 | 4.9 | Schoepite | $4\text{UO}_3 \cdot 9\text{H}_2\text{O}$ (85% U_3O_8) | Diamond- like | Yellow- green |
| 16. | 2-3 | 4 | Renardite | $\text{PbO} \cdot 4\text{UO}_3 \cdot \text{P}_2\text{O}_5 \cdot 9\text{H}_2\text{O}$ (65% U_3O_8) | Greasy | ? |
| 17. | 2-3 | 4 (vari- able) | Carnotite | $\text{K}_2\text{O} \cdot 2\text{UO}_3 \cdot \text{V}_2\text{O}_5 \cdot n\text{H}_2\text{O}$ (50-55% U_3O_8) | Earthy | None |
| 18. | 2-3 | 4 | Beta-uranotile (also orange or yellow- green) | $\text{CaO} \cdot 2\text{UO}_3 \cdot 2\text{SiO}_2 \cdot 6\text{H}_2\text{O}$ (60% U_3O_8) | Pearly | ? |
| 19. | 2-3 (Finger nail = 2.5) | 3.8-3.9 | Uranophane (also pale green or orange) | $\text{CaO} \cdot 2\text{UO}_3 \cdot 2\text{SiO}_2 \cdot 6\text{H}_2\text{O}$ (65% U_3O_8) | Pearly to greasy. | None or very faint |
| 20. | 2-2.5 | 3.2 ± | Johannite (also green) | $\text{CuO} \cdot 2\text{UO}_3 \cdot 2\text{SO}_3 \cdot 7\text{H}_2\text{O}$ (55% U_3O_8) | Vitreous | None |
| 21. | 2-3 | 3.5-3.75 | Sklodowskite | $\text{MgO} \cdot 2\text{UO}_3 \cdot 2\text{SiO}_2 \cdot 7\text{H}_2\text{O}$; Cu may partially replace Mg (65% U_3O_8) | Glassy; pearly | ? |
| 22. | 2-3 | 3.5 | Zippeite | See Orange Minerals (Group 4) | | |

RADIOACTIVE MINERALS IDENTIFICATION TABLE

GROUP 3—YELLOW MINERALS

| Fracture | Streak | Habit | Mode of Occurrence | Remarks |
|----------|----------------------|--|---|--|
| - - - - | Yellow | Minute tabular crystals | Alteration product of uraninite. | Occurs in both vein and bedded deposits associated with uraninite and carnotite. |
| - - - - | Yellow | Tabular or short prismatic crystals. | Alteration product of uraninite. | Crystals commonly have inclusions. |
| - - - - | Yellow | Minute, flat, rectangular prisms. | A very rare secondary uranium mineral. | - - - - |
| - - - - | Yellow | Thin coatings. | In sandstones; often associated with fossil logs and bones. | Color sometimes dulled or concealed by organic or iron staining or by dark vanadium minerals. In such cases ore may be brown, black, or greenish. Soluble in HCl. |
| - - - - | Pale yellow | Velvety radiating groups of prismatic and needle-like crystals. | Alteration product of uraninite and gummite. | Same composition as uranophane. |
| - - - - | Pale yellow | Radiating groups of minute needle-like crystals; occasionally massive and fibrous. | In veins, pegmatites, granites, limestones. | A common secondary uranium mineral; alteration product of uraninite, gummite and other uranium minerals. Same composition as beta-uranotile. Turns black and yields water in blow-pipe flame. Infusible. Gelatinizes in HCl. |
| - - - - | Pale yellow to green | Minute lath-like crystals. | Associated with other secondary uranium minerals. | When heated in closed tube, gives off H ₂ O and SO ₂ , becomes brown and then black. Infusible. Soluble in HCl. |
| - - - - | Pale yellow | Clusters of minute, radiating, prismatic to needle-like crystals; also felt-like coatings. | With other secondary uranium minerals. | Soluble in HCl. |
| | | | | |

RADIOACTIVE MINERALS IDENTIFICATION TABLE

GROUP 3—YELLOW MINERALS

| | Hard- ness | Approx. Specific Gravity | Name | Chemical Composition | Luster | Fluores- cence |
|-----|---------------|--------------------------------|--|--|------------------|----------------------------------|
| 23. | 2-3 | 3-4 (vari- able) | Tyuyamunite (greenish tinge) | $\text{CaO} \cdot 2\text{UO}_3 \cdot \text{V}_2\text{O}_5 \cdot n\text{H}_2\text{O}$ (48-55% U_3O_8) | Earthy | None |
| 24. | 2-3 | 3.45 | Uranospinite (Meta-urano- spinite) (also pale green) | $\text{CaO} \cdot 2\text{UO}_3 \cdot \text{As}_2\text{O}_5 \cdot n\text{H}_2\text{O}$ (50% U_3O_8) | Pearly | Bright greenish yellow |
| 25. | 2-2.3 | 3.5 | Uranocircite (Meta-urano- circite) (yellow to yellow green) | $\text{BaO} \cdot 2\text{UO}_3 \cdot \text{P}_2\text{O}_5 \cdot n\text{H}_2\text{O}$ (50% U_3O_8) | Pearly | Vivid greenish yellow |
| 26. | 2-3 | 3.3 (vari- able) | Troegerite | $3\text{UO}_3 \cdot \text{As}_2\text{O}_5 \cdot n\text{H}_2\text{O}$ (60% U_3O_8) | Pearly | ? |
| 27. | 2-2.5 | 3-3.2 | Autunite (Meta-autunite) (lemon yellow to apple green) | $\text{CaO} \cdot \text{UO}_3 \cdot \text{P}_2\text{O}_5 \cdot n\text{H}_2\text{O}$ (60% U_3O_8) | Pearly | Brilliant yellow or green. |
| 28. | 2-3 | 3.3 | Phosphuranylite (deep lemon yellow) | $3\text{UO}_3 \cdot \text{P}_2\text{O}_5 \cdot 6\text{H}_2\text{O}$ (70% U_3O_8) | Pearly | ? |
| 29. | 1 | 2.5 | Schroeckingerite (also yellow- green) | Water-rich carbonate and sulfate of calcium, sodium and uranium (30% U_3O_8) | Pearly | Bright yellowish green |
| 30. | ? | ? | Dumontite | $2\text{PbO} \cdot 3\text{UO}_3 \cdot \text{P}_2\text{O}_5 \cdot 5\text{H}_2\text{O}$ (50% U_3O_8) | Diamond- like | None |
| 31. | Soft | | Uvanite | See Brown Minerals (Group 2) | | |

RADIOACTIVE MINERALS IDENTIFICATION TABLE

GROUP 3—YELLOW MINERALS

| Fracture | Streak | Habit | Mode of Occurrence | Remarks |
|----------|--------------------------------------|--|---|---|
| - - - - | Yellow | Earthy masses and scales or coatings. | In sandstones; often associated with fossil logs and bones. | Analogous to carnotite with calcium substituting for potassium. Often associated with carnotite and difficult to distinguish from it. Easily fusible. |
| - - - - | Pale yellow | Rectangular, mica-like masses or tabular crystals | Alteration product of primary minerals; | A very rare mineral. The same crystal form as autunite in which phosphorus substitutes for arsenic. Fusible. Soluble in HCl. |
| - - - - | Pale yellow or greenish yellow. | Square, rectangular, or octagonal flat crystals or mica-like masses. | A very rare secondary mineral | Soluble in HCl. |
| - - - - | Pale yellow | Thin tabular crystals resembling gypsum. | With other secondary uranium minerals. | A rare mineral. Soluble in HCl. |
| - - - - | Colorless to pale yellow or greenish | Rectangular, mica-like masses or tabular crystals. | Associated with uraninite, gummite, uranophane; in oxidized zone of most uranium deposits. | A common secondary uranium mineral. The same crystal form as uranospinite in which arsenic substitutes for phosphorus. Yields water when heated in closed tube. Soluble in HCl. |
| - - - - | Yellow | Powdery crusts composed of square or rectangular tablets or plates. | A rare alteration product of primary and some secondary uranium minerals. | When heated in closed tube, yields water and becomes brownish yellow on cooling. Soluble in HCl. |
| - - - - | Pale yellow or greenish yellow. | Small rounded masses composed of flaky crystals, hexagonal mica-like plates. | As pellets in gypsum-bearing, sandy clay; as coatings in the oxidized zones of vein deposits. | Soluble in water |
| - - - - | Pale yellow | Flattened prismatic crystals. | In cavities in torbernite. | A very rare secondary mineral. |
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RADIOACTIVE MINERALS IDENTIFICATION TABLE

GROUP 4—ORANGE MINERALS

| | Hard- ness | Approx. Specific Gravity | Name | Chemical Composition | Luster | Fluores- cence |
|----|------------------------|--------------------------------|---|---|--|---------------------|
| 1. | (Glass = 5-5.5) 4-5 | 7 ± | Curite | $2\text{PbO} \cdot 5\text{UO}_3 \cdot 4\text{H}_2\text{O}$ (70% U_3O_8) | Diamond- like | None |
| 2. | 4-6 | variable | Gummite (also brown, red, yellow) | $\text{UO}_3 \cdot n\text{H}_2\text{O}$ with Pb, Ca, Ba, Si, P, Mn, Fe. (Up to 80% U_3O_8 and 20% ThO_2) | Waxy, dull, greasy; oc- asionally glassy. | None |
| 3. | 4.5-5 (Copper = 3) | 4-6 | Orangeite (Thorite) | See Black Minerals (Group 1) | | |
| 4. | 2-3 | 4 | Beta-uranotile | See Yellow Minerals (Group 3) | | |
| 5. | 2-3 | 3.8-3.9 | Uranophane | See Yellow Minerals (Group 3) | | |
| 6. | 2-3 | 3.5 (vari- able) | Zippeite (also yellow) | $2\text{UO}_3 \cdot \text{SO}_3 \cdot n\text{H}_2\text{O}$ (70% U_3O_8) | Earthy or glassy | Brilliant green. |

RADIOACTIVE MINERALS IDENTIFICATION TABLE

GROUP 4—ORANGE MINERALS

| Fracture | Streak | Habit | Mode of Occurrence | Remarks |
|----------------------|---------------------------------------|--|--|---|
| - - - - | Orange | Massive, earthy, or in clusters of fine needles | An alteration product of uraninite. | A rare mineral in the oxidized zone of primary deposits. Blackens in blowpipe flame. Soluble in HCl and yields chlorine gas. Infusible. |
| Conchoidal to uneven | Orange, yellowish, brownish, greenish | Massive | An alteration product of uraninite and pitchblende. | Commonly associated with uraninite and pitchblende in oxidized zones of pegmatites and veins. Brittle. |
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| - - - - | Yellow | Earthy or powdery; also minute lath-like crystals. | An alteration product of pitchblende and as a coating in asphaltic sandstones. | - - - - |

RADIOACTIVE MINERALS IDENTIFICATION TABLE

GROUP 5—GREEN MINERALS

| | Hard- ness | Approx. Specific Gravity | Name | Chemical Composition | Luster | Fluores- cence |
|-----|-----------------------------------|--------------------------------|---|---|--------------------------|-------------------|
| | (Quartz = 7) | | | | | |
| 1. | 6.5-7 (Knife blade = 5.5-6) | 4-4.5 | Gadolinite (deep green to black or brown, yellow brown, or brick red) | Silicate of iron, beryllium, and rare earths. (Up to 12% BeO, 2% ThO ₂ , and 0.5% U ₃ O ₈) | Glassy to dull | None |
| 2. | 5-6 (Glass = 5-5.5) | 4-6 | Pyrochlore- microlite | See Brown Minerals (Group 2) | | |
| 3. | 5.5-6 | 3-4 | Allanite | See Brown Minerals (Group 2) | | |
| 4. | 4.5-5 | 4-6 | Thorite | See Black Minerals (Group 1) | | |
| 5. | 4-5 | 4.5 | Xenotime | See Yellow Minerals (Group 3) | | |
| 6. | 3-6 (Copper = 3) | 3.6-4.1 | Naegite (also brown or reddish brown) | ZrSiO ₄ with minor rare earths. (Up to 3% U ₃ O ₈ ; 5% ThO ₂) | Dull to sub- resinous | - - - - |
| 7. | 2-3 | 4 | Beta-uranotile | See Yellow Minerals (Group 3) | | |
| 8. | 2-3 | 3.8-3.9 | Uranophane | See Yellow Minerals (Group 3) | | |
| 9. | 2-3 | 3.45 | Uranospinite | See Yellow Minerals (Group 3) | | |
| 10. | 2-3 (Finger nail = 2.5) | 3.2 | Zeunerite (Meta-zeunerite) | CuO.2UO ₃ .As ₂ O ₅ .nH ₂ O (50% U ₃ O ₈) | Pearly, glassy | None |
| 11. | 2-2.5 | 3.5 | Uranocircite | See Yellow Minerals (Group 3) | | |
| 12. | 2-2.5 | 3.2-3.6 | Torbernite (Meta-torbernite) | CuO.2UO ₃ .P ₂ O ₅ .nH ₂ O (60% U ₃ O ₈) | Pearly | None |
| 13. | 2-2.5 | 3.2-4 | Johannite | See Yellow Minerals (Group 3) | | |
| 14. | 2-2.5 | 3-3.2 | Autunite | See Yellow Minerals (Group 3) | | |
| 15. | 1 | 2.5 | Schroëckingerite | See Yellow Minerals (Group 3) | | |

RADIOACTIVE MINERALS IDENTIFICATION TABLE

GROUP 5—GREEN MINERALS

| Fracture | Streak | Habit | Mode of Occurrence | Remarks |
|-------------------------|--|--|---|---|
| Conchoidal to splintery | Greenish gray when fresh; yellow brown to red brown when altered | Massive or in rough crystals | Pegmatites | Infusible. In the blowpipe flame, gives a temporary bright light, swells and cracks open. Gelatinizes in HCl. |
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| Conchoidal | Pale green, brown, or red | Long, square prismatic crystals with pyramidal terminations. | Pegmatites; placers | A variety of zircon. |
| | | | | |
| | | | | |
| | | | | |
| - - - - | Pale green | Square plates; mica-like masses. | With other uranium minerals, especially associated with arsenic minerals. | Very similar in appearance to torbernite, but much less common. Soluble in HNO_3 . |
| | | | | |
| - - - - | Pale green | Square plates; mica-like masses. | With other uranium minerals, especially associated with copper minerals. | A very common secondary mineral. Yields water when heated in closed tube. Soluble in HCl. |
| | | | | |
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RADIOACTIVE MINERALS IDENTIFICATION TABLE

GROUP 6—RED MINERALS

| | Hard- ness | Approx. Specific Gravity | Name | Chemical Composition | Luster | Fluores- cence |
|----|--------------------------------|--------------------------------|--|--|------------------|-------------------|
| 1. | 6.5-7 (Knife blade = 5.5-6) | 4-4.5 | Gadolinite | See Green Minerals (Group 5) | | |
| 2. | 5-6 | 4-6 | Pyrochlore- microlite | See Brown Minerals (Group 2) | | |
| 3. | 4-6 (Glass = 5-5.5) | variable | Gummite | See Orange Minerals (Group 4) | | |
| 4. | 3-4 | 6 | Fourmarierite (also golden red or brown) | $PbO \cdot 4UO_3 \cdot 5H_2O$ (70% U_3O_8) | Diamond- like | None |
| 5. | 3-6 | 3.6-4.1 | Naegite | See Green Minerals (Group 5) | | |
| 6. | 3-6 (Copper = 3) | 3.6-4.1 | Cyrtolite | See Brown Minerals (Group 2) | | |

GROUP 7—COLORLESS MINERALS

| | Hard- ness | Approx. Specific Gravity | Name | Chemical Composition | Luster | Fluores- cence |
|----|---------------|--------------------------------|-----------------------------------|------------------------------|--------|----------------------------------|
| 1. | | 7 ± | Huttonite (also pale cream) | $ThSiO_4$ (76% ThO_2) | Glassy | Dull white with pink tinge |
| 2. | 5-6 | 4-6 | Pyrochlore- microlite | See Brown Minerals (Group 2) | | |
| 3. | 3-6 | 3.6-4.1 | Cyrtolite | See Brown Minerals (Group 2) | | |

RADIOACTIVE MINERALS IDENTIFICATION TABLE

GROUP 6—RED MINERALS

| Fracture | Streak | Habit | Mode of Occurrence | Remarks |
|----------|-----------------------|----------------|-------------------------------------|--|
| | | | | |
| | | | | |
| | | | | |
| ---- | Red to reddish brown. | Tabular plates | An alteration product of uraninite. | A rare mineral. Infusible. Soluble in HCl. |
| | | | | |
| | | | | |

GROUP 7—COLORLESS MINERALS

| Fracture | Streak | Habit | Mode of Occurrence | Remarks |
|------------|--------|-------|---|---|
| Conchoidal | ---- | ---- | Minute, uneven-edged grains in placers. | A rare mineral associated with uranothorite in placers. |
| | | | | |
| | | | | |

Appendix IV—Lindgren Classification of Mineral Deposits

Lindgren¹ established a detailed classification of mineral deposits, taking into account the process of concentration and the relationship to the enclosing rock. This is given below with specific examples provided by the author, including, when possible, examples of deposits of atomic energy minerals. In this classification you will note that those deposits formed at the end of the geologic cycle and, with few exceptions, nearest the surface of the earth at the time of formation, are listed first.

SECONDARY SYNGENETIC DEPOSITS²

I. Deposits produced by mechanical processes of concentration. (Temperature and pressure moderate.) Placer gold deposits of California and Alaska. Monazite-bearing beach sand deposits of Brazil and India.

II. Deposits produced by chemical processes of concentration. (Temperature and pressure vary between wide limits.)

A. In bodies of surface water. (Temperature, 0° to 70°C.±; pressure, moderate to strong.)

1. By interaction of solutions.

a. Inorganic reactions.

Clinton iron ores, Birmingham district, Alabama. Uranium-bearing phosphate rocks (phosphorites) of Florida, Montana, Idaho, Wyoming, and Utah.

b. Organic reactions.

Coal and petroleum deposits. Uranium-bearing Chattanooga shale of Tennessee and alum (Kölm) shale of Sweden.

2. By evaporation of solvents.

Texas-New Mexico potash deposits.

Wamsutter, Wyoming, schroeckingerite deposit.

B. In bodies of rocks.

1. By concentration of substances contained in the geologic body (rock) itself.

a. Concentration by rock decay and residual weathering near surface. (Temperature 0°-100°C.±; pressure, moderate.)

Appalachian iron ores and Arkansas bauxite deposits.

SECONDARY EPIGENETIC DEPOSITS²

b. Concentration by ground water of deeper circulation. (Temperature, 0°-

100°C.±; pressure, moderate.)

Kennecott copper mine, Copper River Region, Alaska; southern Appalachian barite deposits.

Kara-Tau and Tyuya Muyun uranium deposits of U.S.S.R.(?), and Colorado Plateau carnotite deposits(?).

c. Concentration by dynamic and regional metamorphism. (Temperature up to 400°C.±; pressure, high.)

Lake Superior iron ores.

2. Concentration effected by introduction of substances foreign to the rock.

a. Origin independent of igneous activity. By circulating atmospheric waters at moderate or slight depth. (Temperature to 100°C.±; pressure moderate.)

The Mississippi Valley lead-zinc ores and the Colorado Plateau carnotites may have been formed in this manner. Kara-Tau and Tyuya Muyun deposits(?).

PRIMARY EPIGENETIC DEPOSITS²

b. Origin dependent upon igneous activity.

(1) By hot ascending waters of uncertain origin, but charged with igneous emanations (hydrothermal solutions)².

(a) Deposition and concentration at slight depth. Epithermal deposits. (Temperature, 50°-200°C.±; pressure, moderate.) Almaden, Spain, and New Almaden, California quicksilver (mercury) deposits. Gold-silver mines of Tonapah district, Nevada. Gold telluride veins, Cripple Creek district, Colorado.

(b) Deposition and concentration at intermediate depths. Mesothermal deposits. (Temperature, 200°-300°C.±; pressure, high.) Gold-quartz veins of Sierra Nevada, California, and Victoria, Australia.

Silver-lead limestone replacement deposits of Park City and Tintic, Utah, and Leadville, Colorado. Pitchblende deposits at Shinkolobwe, Belgian Congo; Joachimsthal, Czechoslovakia; and Great Bear Lake, N.W.T., Canada.

(c) Deposition and concentration at great depth or at high temperature

¹ By permission from *Mineral Deposits*, 4th Revised Ed., Waldemar Lindgren, McGraw-Hill Book Co., Inc., 1933.

² Added by author.

SAMPLE TESTING AND ANALYSIS

and pressure. Hypothermal deposits. (Temperature, 300° - $500^{\circ}\text{C}.$; pressure, very high.) Cassiterite (tin oxide) deposits of Cornwall, England, and Bolivia. Gold-quartz veins of Ontario, Canada. Lead-zinc deposits at Broken Hill, N.S.W., Australia.

(2) By direct igneous emanations.

(a) From intrusive bodies. Contact metamorphic or pyrometasomatic deposits. (Alteration and mineralization of enclosing rock at or near contact with molten magma.)¹ (Temperature, probably 500° - $800^{\circ}\text{C}.$; pressure, very high.) Magnetite (iron oxide) deposit at Cornwall, Penn. Peripheral copper deposits at Bisbee and Clifton, Ariz. Zinc deposit at Franklin Furnace, New Jersey.

(b) From effusive bodies. Sublimates, furmaroles. (Surface volcanic activity; hot springs, etc.)¹ (Temperature, 100° - $600^{\circ}\text{C}.$; pressure, atmospheric to moderate.) Minor deposits of sulfur (Vesuvius, Italy, and Popocate-

petl, Mexico), mercury, arsenic, and antimony.

PRIMARY SYNGENETIC DEPOSITS¹

C. In magmas, by processes of differentiation.

(a) Magmatic deposits proper.

(Temperature, 700° - $1500^{\circ}\text{C}.$; pressure, very high.) Diamond deposits of South Africa. Chromite (iron-chromium oxide) deposits of Rhodesia.

Adirondack magnetite deposits of New York. Sudbury, Ontario, nickel deposits.

PRIMARY EPIGENETIC DEPOSITS¹

(b) Pegmatites. (Temperature, about $575^{\circ}\text{C}.$; pressure, very high.) Sources of rare elements, mica and feldspar throughout the world. Beryl deposits of United States, Brazil, India, Africa, etc.; minor uranium and thorium in most pegmatites.

Appendix V—Sample Testing and Analysis

Professional assaying services are provided by a large number of private firms throughout the country. In addition, the U. S. Geological Survey, the U. S. Bureau

of Mines, and some State mining and geological agencies will examine samples for uranium or thorium without charge.

SENDING SAMPLES FOR ASSAY

Samples submitted to the U. S. Geological Survey should be addressed as follows:

U. S. Geological Survey
Geochemistry and Petrology Branch
Building 213, Naval Gun Factory
Washington 25, D. C.

Samples submitted to the U. S. Bureau of Mines should be addressed to one of the following:

Regional Director, Region II
U. S. Bureau of Mines
Albany, Oregon

Chief, Electrometallurgical Branch
Metallurgical Division, Region III
U. S. Bureau of Mines
Boulder City, Nevada

Chief, Hydrometallurgical & Ore Dressing Branch
Metallurgical Division, Region III
U. S. Bureau of Mines
Reno, Nevada

Chief, Chemical & Physical Analysis Branch
Metallurgical Division, Region IV
U. S. Bureau of Mines
Salt Lake City, Utah

Chief, Process Development & Research Branch
Metallurgical Division, Region IV
U. S. Bureau of Mines
Tucson, Arizona

Chief, Metallurgical Division, Region V
U. S. Bureau of Mines
University Campus
Minneapolis 14, Minnesota

¹ Added by author.

APPENDIX V

Chief, Minerals Technology Division, Region VI
U. S. Bureau of Mines
Rolla, Missouri

Chief, Metallurgical Division, Region VII
U. S. Bureau of Mines
University, Alabama

Chief, Metallurgical Division, Region VIII
U. S. Bureau of Mines
College Park, Maryland

Samples should weigh at least 1 pound, should be carefully wrapped in a strong package, and should be clearly labeled with the sender's return address. If more than one sample is submitted in the same package, each sample should be numbered. Each sample should also be a representative one; that is, it should represent, as fairly and as accurately as possible, the rocks of the entire deposit from which it was taken. If one part of the deposit appears to be more radioactive than another, rocks taken from both parts should be included in the sample. If a small amount of high-grade ore is submitted, it should be stated that the sample is not representative of the entire deposit, but only of a small portion of it.

The results of assays are reported to the individual submitting the sample and to the Atomic Energy Commission if the sample shows radioactivity.

It is desirable to include the following specific information with each sample:

1. The sample number, if more than one sample is submitted in the same package.
2. The exact location from which the sample was obtained, including the state, county, nearest town, claim name (if any), mine name (if any), and the section, township and range (if known).
3. The estimated amount of material represented by the sample; that is, the length, width, and depth of the deposit insofar as they can be determined.
4. Previous tests made on the sample.
5. Information on the proportion of the original sample that the submitted sample represents if the submitted sample has been concentrated.
6. Other materials, if any, being mined from the place from which the sample was obtained.
7. Other relevant information, including a short description of the deposit.

COMMERCIAL ASSAYERS OF URANIUM

Abbot A. Hanks
624 Sacramento Street
San Francisco 11, California

H. D. Brown Laboratory
Route 3
Grand Junction, Colorado

Ledoux & Company
359 Alfred Avenue
Teaneck, New Jersey

Lucius Pitkin
47 Fulton Street
New York 7, New York

Smith-Emery Company
920 Santee Street
Los Angeles 15, California

Livingston Uranium Company
Edgemont, South Dakota

Charles O. Parker
Denver, Colorado

Smith's Laboratory
Moab, Utah

Horace J. Hallowell
Analytical and Consulting Chemist
323 Main Street
Danbury, Connecticut

Dickinson Laboratories
1300 W. Main Street
El Paso, Texas

QUESTIONS AND ANSWERS

STANDARD SAMPLES

Standard samples, ground to a fine powder and suitable for analytical work or for comparison purposes, are available at:

New Brunswick Laboratory
U. S. Atomic Energy Commission
P. O. Box 150
New Brunswick, New Jersey

Samples of the following ores are available:

| | <i>Percent U₃O₈</i> |
|----------------------------|---|
| Phosphate rock, No. 1..... | 0.03 |
| Pitchblende, No. 3..... | 3.4 |
| Carnotite, No. 4..... | 0.17 |
| Carnotite, No. 5..... | 0.12 |

The cost of these analyzed samples is:

\$2.50 per 100 g sample.
\$5.00 per 200 g sample.

Standard samples for counter calibration are available from:

The Radiac Company
489 Fifth Ave.
New York 17, New York

SPECIMENS OF URANIUM, THORIUM, AND BERYLLIUM MINERALS

Specimens of minerals may be bought from mineral dealers. Also, many museums in the larger cities display specimens in their mineralogical exhibits. Among the mineral dealers from which mineral specimens can be purchased are:

Grieger's
1633 East Walnut Street
Pasadena 4, California

V. D. Hill
Route 7, Box 188
Salem, Oregon

A. D. Mackay
198 Broadway
New York 7, New York

Schortman's Minerals
6 and 10 McKinley Avenue
Easthampton, Massachusetts

Ward's Natural Science Establishment
P. O. Box 24, Beechwood Station
Rochester 9, New York

Walker's Minerals
1040 Ave. of Americas
New York 18, New York

Plummer's
2183 Bacon Street
San Diego 7, California

*Appendix VI—Questions and Answers**

QUESTION: *Will the Government rent or lend me a Geiger counter or other prospecting or mining equipment?*

ANSWER: The Government does not have such equipment available for rental or loan. All equipment necessary or desirable for uranium prospecting, including Geiger counters, is available from commercial dealers.

QUESTION: *Is it dangerous to prospect for radioactive minerals?*

ANSWER: It is no more dangerous to prospect for radioactive minerals than it is to prospect for other types of minerals. The radioactivity contained in rocks is not

dangerous to humans unless such rocks are held in close contact with the skin for very long periods of time.

QUESTION: *Does the glow that comes from decayed logs or stumps at night mean that uranium is present?*

ANSWER: Phosphorescence, not fluorescence, may cause such a glow, and this does not mean that uranium is present. Fluorescence cannot be observed except under an ultraviolet lamp.

QUESTION: *Do I have to report uranium discoveries to the Atomic Energy Commission?*

* From *Prospecting for Uranium*, published by the U. S. Atomic Energy Commission and the U. S. Geological Survey, U. S. Government Printing Office, Washington, D. C., 1951.

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ANSWER: No, although such reporting is encouraged. A license from the Commission is needed, however, before uranium that has been mined can be sold or transferred.

QUESTION: *Will the Government buy my land if uranium is found on it, and, if not, will the Government take over the land and mine the uranium for me?*

ANSWER: In accordance with its policy to encourage the development by private enterprise of the uranium resources of the United States, the Atomic Energy Commission follows the practice of buying uranium ores, concentrates, or refined products after they have been mined or processed.

QUESTION: *Do I lose my mineral rights to a claim on which uranium is discovered?*

ANSWER: The discovery of uranium on a claim staked before August 1, 1946, will make no change in the locator's rights except that a license is needed to sell or transfer the ore after it has been mined. If uranium is discovered on a claim staked on or after August 1, 1946, the locator will have valuable rights in the uranium deposits but the Government will also keep some rights in the ore. The rights of the locator and the rights of the Government in uranium deposits located after August 1, 1946, are described in Chapter VI, "Laws and Regulations." [Appendix IX in this book.]

QUESTION: *If I find uranium on my property, must I sell it to the Atomic Energy Commission only, or may I sell it to someone else?*

ANSWER: Owners may sell uranium to the Commission or to any private buyer, provided both the buyer and seller are licensed by the Commission.

QUESTION: *If the Atomic Energy Commission is not interested in buying uranium*

ore that I own, may I offer it to a private company, either for its uranium content or for other minerals that it may contain?

ANSWER: Yes. However, licensing regulations must be observed.

QUESTION: *Is the Atomic Energy Commission interested in other ores, metals, or minerals that I find or own?*

ANSWER: No. The Commission is directly interested almost wholly in uranium, although it also appreciates receiving information about thorium deposits. Inquiries concerning other ores, minerals, and metals should be addressed to the U. S. Geological Survey or the U. S. Bureau of Mines, both at Washington 25, D. C.

QUESTION: *Is the Atomic Energy Commission interested in foreign uranium ores?*

ANSWER: The Commission will examine samples of such ores, and consider buying them if, under the regulations of the foreign government concerned, they can be delivered to the Commission. The bonus offers do not apply to foreign ores.

QUESTION: *What methods are used to mine and concentrate uranium ores?*

ANSWER: In general, the same methods, techniques, and skills used in mining the ore of any metal are necessary for mining uranium. The specific methods used depend upon the type of deposit. When a commercially valuable deposit is found, the advice of technically qualified specialists is required to determine the best method of mining and concentrating the uranium ore.

QUESTION: *May I take or ship a Geiger counter out of the United States to another country to prospect for uranium?*

ANSWER: An Atomic Energy Commission license to export a Geiger counter must be obtained prior to taking or shipping a counter out of the United States.

*Appendix VII—Sources of Additional
Information and Aid*

GENERAL INFORMATION

General information may be obtained from the following Atomic Energy Commission offices:

ARIZONA

U. S. Atomic Energy Commission
Division of Raw Materials
Phoenix Sub-office
137 North Second Ave.
Phoenix, Arizona

COLORADO

U. S. Atomic Energy Commission
Division of Raw Materials
Denver Exploration Branch
Building 40
The Federal Center
Denver 15, Colorado

U. S. Atomic Energy Commission
Grand Junction Operations Office
P. O. Box 270
Grand Junction, Colorado

MICHIGAN

U. S. Atomic Energy Commission
Division of Raw Materials
Ishpeming, Sub-office
Room 2, Post Office Building
Ishpeming, Michigan

MONTANA

U. S. Atomic Energy Commission
Division of Raw Materials
Butte Sub-office
Room 315, Post Office Building
Butte, Montana

NEW MEXICO

U. S. Atomic Energy Commission
Division of Raw Materials
Albuquerque Sub-office
142 N. E. Monroe Street
Albuquerque, New Mexico

SOUTH DAKOTA

U. S. Atomic Energy Commission
Division of Raw Materials
Hot Springs Sub-office
Evans Hotel Annex
Hot Springs, South Dakota

UTAH

U. S. Atomic Energy Commission
Division of Raw Materials
Richfield Sub-office
Room 26, C.P.A. Building
Richfield, Utah

U. S. Atomic Energy Commission
Division of Raw Materials
Salt Lake Exploration Branch
222 S. W. Temple
Salt Lake City, Utah

WASHINGTON, D. C.

U. S. Atomic Energy Commission
Division of Raw Materials
Washington 25, D. C.

WYOMING

U. S. Atomic Energy Commission
Division of Raw Materials
Douglas Sub-office
209 East Center Street
Douglas, Wyoming

APPENDIX VII

POSTING OF INFORMATION

The U. S. Atomic Energy Commission releases information concerning the location of surface areas of high radioactivity that have been found by airborne detection instruments and by geological reconnaissance conducted on the ground, if on public land.

Denver Exploration Branch
U. S. Atomic Energy Commission
Denver Federal Center, Bldg. 40,
Denver 15, Colorado

Hot Springs Sub-office
U. S. Atomic Energy Commission
Evans Hotel Annex
Hot Springs, South Dakota

U. S. Bureau of Mines Office
Rapid City, South Dakota

U. S. Geological Survey Office
Custer, South Dakota

Grand Junction Operations Office
U. S. Atomic Energy Commission
Grand Junction, Colorado

U. S. Atomic Energy Commission Buying
Station
Shiprock, New Mexico

Salt Lake Exploration Branch
U. S. Atomic Energy Commission
222 South West Temple
Salt Lake City, Utah

Richfield Sub-office
U. S. Atomic Energy Commission
C.P.A. Bldg., Room 26
Richfield, Utah

U. S. Atomic Energy Commission Buying
Station
Monticello, Utah

Butte Sub-office
U. S. Atomic Energy Commission
Post Office Bldg., Room 315,
Butte, Montana

U. S. Geological Survey Office
Worland, Wyoming

U. S. Geological Survey Office
Casper, Wyoming

Index maps showing the location of such areas are posted simultaneously at noon, Mountain Standard Time, at the following offices¹ on the 15th day of each month (or the first succeeding working day if the 15th falls on Saturday, Sunday, or a Federal holiday).

Albuquerque Sub-office
U. S. Atomic Energy Commission
142 N. E. Monroe St.
Albuquerque, New Mexico

Douglas Sub-office
U. S. Atomic Energy Commission
209 East Center St.
Douglas, Wyoming

Phoenix Sub-office
U. S. Atomic Energy Commission
137 North Second Ave.
Phoenix, Arizona

Ishpeming Sub-office
U. S. Atomic Energy Commission
Post Office Bldg., Room 2,
Ishpeming, Michigan

U. S. Atomic Energy Commission
Grants, New Mexico

Geological Survey of Wyoming
University of Wyoming
Laramie, Wyoming

Copies of these maps may be purchased from the following companies:

Colorado Blue Print Company
1522 Glenarm Place
Denver 2, Colorado

Denver Blue Print Company
728 14th Street
Denver 2, Colorado

Dunkin Blue Print Company
236 Main Street
Grand Junction, Colorado

Hotchkiss Mapping Company
4055 Fox Street
Denver 16, Colorado

Photo-Blue Company
P. O. Box 626
Salt Lake City, Utah

¹ Other temporary locations in areas being surveyed may be added from time to time.

SOURCES OF ADDITIONAL INFORMATION AND AID

Salt Lake Blue Print & Supply Company
245 South State Street
Salt Lake City, Utah

Universal Engineering Supply Company
9625 West Colfax Avenue
Lakewood, Colorado

The Kendrick-Bellamy Company
1641 California Street
Denver, Colorado

Westwide Maps Company
114½ West Third Street
Los Angeles, California

Uranium Prospector Service
503 Rood Avenue
Grand Junction, Colorado

Bell Map Company
314 California Bldg.
710-17th Street
Denver, Colorado

Nielsen Blue Print, Inc.
108 North Third Street
Grand Junction, Colorado

OPEN FILING OF REPORTS

The U. S. Atomic Energy Commission and the U. S. Geological Survey place in open-file reports dealing with exploration for radioactive materials. The reports are available for examination in major city, university, and college libraries throughout the United States and at the following additional locations:

ATOMIC ENERGY COMMISSION OFFICES

Atomic Energy Commission Library
1901 Constitution Avenue, N.W.
Washington 25, D. C.

Division of Raw Materials
Denver Exploration Branch
Building 40
The Federal Center
Denver, Colorado

Division of Raw Materials
Salt Lake Exploration Branch
222 South West Temple
Salt Lake City, Utah

Division of Raw Materials
Grand Junction Operations Office
Grand Junction, Colorado

OTHER OFFICES

Geological Survey Library
Room 1033
General Services Administration Building
Washington, D. C.

Office of the Director
Montana Bureau of Mines and Geology
Butte, Montana

Public Inquiries Office
Room 468, New Customhouse
Denver, Colorado

Geological Survey
Grand Junction, Colorado

Idaho Bureau of Mines and Geology
Moscow, Idaho

Geological Survey
102 Old Mint Building
San Francisco, California

Public Inquiries Office
Room 504 Federal Building
Salt Lake City, Utah

Arizona Bureau of Mines
University of Arizona
Tucson, Arizona

U. S. Geological Survey
South 157 Howard Street
Spokane, Washington

Reports dealing with specific areas or deposits in a state, or including a state, will also be on file at the State Geologist's office.

Appendix VIII

MANUFACTURERS AND DISTRIBUTORS OF GEIGER AND SCINTILLATION COUNTERS

Because of the rapid increase in the number of firms manufacturing and/or distributing counters, this list may not be complete.

In general, prices for portable prospecting instruments range from about \$50 to about \$500. Prices for drill hole and aerial counters are \$500 and up. Prospective purchasers should consult manufacturers' and distributors' catalogs for exact prices and specifications.

The U. S. Atomic Energy Commission publishes a catalog entitled, *Radiation Instrument Catalog* which describes different types of radiation detection instruments and accessories. This catalog is revised periodically and may be obtained for \$2.00 from the Office of Technical Services, Department of Commerce, Washington 25, D. C.

Anton Electronic Laboratories, Inc.
1226-1238 Flushing Ave.
Brooklyn 6, New York

Atomic Instrument Company
84 Massachusetts Ave.
Cambridge 39, Massachusetts

Atomic Research Corporation
Colorado Springs, Colorado

V. G. Baker
Fairbanks, Alaska

Beckman Instruments, Inc.
820 Mission St.
South Pasadena, California

Bendix Aviation Corporation
Red Banks Division
Eatontown, New Jersey

Berkeley Scientific Division of
Beckman Instruments, Inc.
2200 Wright Avenue
Richmond, California

Canadian Aviation Electronics Ltd.
387 Sutherland Ave.
Winnipeg, Manitoba, Canada

The Detectron Company
5631 Cahuenga Blvd.
North Hollywood, California

The E. A. K. Research Laboratory
Tarrytown, New York

Electronic Associates, Ltd.
2760 Yonge St.
Toronto 12, Canada

El-Tronics, Inc.
2647 North Howard Ave.
Philadelphia 33, Pennsylvania

Engineers Syndicate, Ltd.
5011 Hollywood Blvd.
Hollywood, California

Fisher Research Laboratory, Inc.
1961 University Lane
Palo Alto, California

General Electric Company
1 River Road
Schenectady 5, New York

Geophysical Measurements Corp.
801-805 Wright Bldg.
Tulsa 3, Oklahoma

Herbach & Rademan, Inc.
1204 Arch
Philadelphia 6, Pennsylvania

LaRoe Instruments, Inc.
743 Investment Bldg.
Washington, D. C.

Menlo Research Laboratory
P. O. Box 522
Menlo Park, California

Morgan Instruments Company
21420 Valerie St.
Canoga Park, California

Nuclear Enterprises, Inc.
1124 Grosvenor Ave.
Winnipeg, Manitoba, Canada

Nuclear Instrument & Chemical Corp.
223 West Erie St.
Chicago 7, Illinois

MANUFACTURERS AND DISTRIBUTORS OF COUNTERS

Nuclear Measurements Corporation
2460 North Arlington Avenue
Indianapolis 18, Indiana

Nuclear Research Corporation
2563 Grays Ferry Ave.
Philadelphia 46, Pennsylvania

Nucleonic Company of America
497 Union St.
Brooklyn 31, New York

Omaha Scientific Supply Corp.
3623 Lake St.
(Mail address: Box 1706)
Omaha 4, Nebraska

Plummer's
2183 Bacon St.
San Diego 7, California

Precision Radiation Instruments
2235 South La Brea
Los Angeles 16, California

Professional Equipment Co.
149 Broadway
New York, N. Y.

R-C Scientific Instrument Co., Inc.
335 Culver Blvd.
Playa Del Rey, California

The Radiac Co.
489 Fifth Ave.
New York 17, New York

Radiation Counter Laboratories, Inc.
5122 West Grove St.
Stokie, Illinois

Sears Roebuck and Company

Service Diamond Tool Company
Radioactivity Instrument Division
2505 Burdette Ave.
Ferndale 20, Michigan

Special Instruments Laboratory, Inc.
1003 Highland Ave.
Knoxville, Tennessee

Technical Associates
140 West Providencia Ave.
Burbank, California

Tracerlab, Inc.
130 High St.
Boston 10, Massachusetts

Victoreen Instrument Company
3800 Perkins Avenue
Cleveland, Ohio

Walker's Minerals
1040 Ave. of Americas
New York 18, N. Y.

Western Radiation Laboratory
1107 West 24th St.
Los Angeles 7, California

Whites Electronics
1218 M Street
Sweet Home, Oregon

COMPANIES EQUIPPED TO DO AERIAL RADIOACTIVITY SURVEYS

Aeromagnetic Surveys, Ltd.
1450 O'Connor Drive
Toronto, Canada

Aero Service, Inc.
236 E. Courtland Street
Philadelphia 20, Pennsylvania

Canadian Air Services, Ltd.
348 Queen Street
Ottawa, Canada

Fairchild Aerial Surveys, Inc.
30 Rockefeller Plaza
Room 4628
New York 20, New York

American British Electric Corporation
57 Park Avenue
New York 16, New York

Hunting Aerosurveys, Ltd.
6 Elstree Way
Elstree, Hants.
England

Appendix IX—Laws and Regulations Applying to Prospecting in the United States

LAWS AND REGULATIONS*

The Federal, State, and local prospecting and mining regulations which apply to metallic ores generally also apply to the uranium-bearing and thorium-bearing ores. Because uranium and thorium ores can be used as source materials in the production of atomic energy, they are also subject to certain other controls which stem from provisions of the Atomic Energy Act, effective August 1, 1946. These special controls, however, apply for the most part to the sale or transfer of uranium and thorium ores after they have been removed from the ground, and generally will not interfere with normal prospecting and mining operations. Actually, it is the policy of the Federal Government to encourage, rather than to restrict, the independent prospecting for and the independent mining, processing, and sale of uranium.

LICENSES

No Federal Government license or permit is needed to prospect for or mine uranium or thorium on public or private lands, except in those places, such as certain Indian Reservations, where prospecting or mining permits are required generally. In order to prospect on State or privately owned lands, the permission of the owner of the land or mineral rights is needed. In the case of State lands, this will be the State government.

On Indian Reservations, a permit to prospect for any type of ore must be obtained from the superintendent of the reservation. If a discovery is made, an application for a lease may be sent to the Bureau of Indian Affairs, Department of the Interior, Washington 25, D. C. There is one exception to this rule: no permit is needed to prospect on the Papago Indian Reservation in southern Arizona, although the locator must furnish the superintendent with a copy of his location notice within 90 days after filing.

No license or permit is needed to lease or purchase mining rights to uranium or thorium in privately owned lands or in loca-

tions on the public domain. Arrangements for the lease or purchase of mining rights for these metals may be made between persons in the same manner as if the lands contained no uranium or thorium.

A license from the Atomic Energy Commission is needed to sell, transfer, or receive uranium and thorium ores which have been removed from the ground, no matter where or when they were mined. The procedures for obtaining this license, which are simple to follow, are included in a regulation issued by the Commission. The ores subject to licensing—called "source materials"—are those that contain by weight 0.05 percent or more of uranium or thorium or any combination thereof. A license may be issued to authorize a single transfer or continuing transfers.

Licensing regulations do not apply to very limited movements of uranium or thorium which do not involve the transfer of control, possession, or title to another person, firm, or corporation. This means, for example, that a company owning several mines may collect and move ore from these mines to a central stock pile on its own property without obtaining a license from the Commission.

PUBLIC LANDS

The vacant and unappropriated public lands (including lands in national forests, except those acquired under the act of March 1, 1911, known as the Weeks Act, and other repurchased lands) in the States of Arizona, Arkansas, California, Colorado, Florida, Idaho, Louisiana, Mississippi, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oregon, South Dakota, Utah, Washington, and Wyoming, and the Territory of Alaska, are open to prospectors for uranium and thorium, and a valid claim based upon the presence of these metals may be located.

Certain national monuments and one national park are also open to prospectors. These are Mt. McKinley National Park

* From *Prospecting for Uranium*, published by the U. S. Atomic Energy Commission and the U. S. Geological Survey, U. S. Government Printing Office, Washington, D. C., 1951.

LAWS AND REGULATIONS APPLYING TO PROSPECTING

and Glacial Bay National Monument in Alaska, Organ Pipe Cactus National Monument in Arizona, and Death Valley National Monument in California. Mining locations may not be made on lands in any other national park or monument.

The Atomic Energy Commission, in cooperation with the U. S. Geological Survey, is carrying on diamond drilling and geological surveys on certain public lands in the Colorado Plateau area and elsewhere. In order to aid this official exploration program, the Department of the Interior, under the public land laws, has withdrawn from entry and appropriation approximately 150 square miles of public land in southwestern Colorado and southeastern Utah. These withdrawn lands are described in Public Land Orders 459, 494, 565, and 698. Lands covered by these orders on which further exploration is not planned will be released from the withdrawal orders and again will be open for entry. It is expected that lands found to contain uranium will become available for development and mining by private interests under arrangements with the Commission.

The principal difference between prospecting for uranium and thorium ores and prospecting for other metallic ores on public lands arises from the Atomic Energy Act, which provides that all uranium and thorium on those public lands which were vacant and unappropriated on August 1, 1946, when the act became effective, is reserved "for the use of the United States." It is the view of the Atomic Energy Commission and the Department of the Interior, however, that this provision does not prevent the staking of a valid claim as a result of the discovery of uranium or thorium, and will generally not prevent the locator from mining or selling the ore.

STAKING CLAIMS

If a citizen, or a person who has declared his intention to become a citizen, discovers uranium or thorium on the vacant and unappropriated public lands, he may stake a claim in exactly the same way as for copper, gold, or any other valuable metal.

Many uranium-bearing or thorium-bearing ores also contain other valuable metals. In these cases, a valid claim may be staked on the basis of the discovery of

the whole ore, or of any metal or combination of metals that may have commercial value. As a rule, it is not necessary for the locator to name in the location certificate the valuable metal upon which his claim is based.

He may merely state that the claim contains "valuable minerals." Where he desires, or is required, to name a specific metal in a location certificate or application for patent, it is permissible for him to use uranium or thorium as the basis for his claim, or if he desires, to specify any of the other valuable metals or combination of metals that are present in the ore. For example, in the carnotite areas of western Colorado, a valid claim, which may be reduced to patent, may be based on either the uranium or the vanadium content of the ore or on both metals.

The standard procedures for staking claims on the public lands of the United States and Alaska are outlined in Circular No. 1278 of the Bureau of Land Management. The rules stated there are applicable to uranium and thorium ores.

GOVERNMENT RIGHTS AND POWERS

Because of the provisions of the Atomic Energy Act, the Government keeps certain rights in uranium or thorium ores located on public lands after August 1, 1946. The most important of these is the right of the Atomic Energy Commission to enter on the land subject to the location and remove the uranium or thorium ore. If this right of entry is used, the Commission is required by law to compensate the locator for the damage or injury caused by its action, although not for the uranium or thorium which is removed. For example, in the case of a carnotite deposit, the Commission would be required to pay the claim holder for the vanadium which would be removed along with the uranium, but not for the uranium content of the ore. This right of the Commission to enter and remove ores which contain uranium or thorium protects the Government from, among other things, a claim holder's refusal to work a deposit.

Under the provisions of the Atomic Energy Act, the Atomic Energy Commission may also, if it considers it necessary, require the delivery to the Commission of uranium or thorium, located on public

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lands after August 1, 1946, after the metal has been mined and separated. If the Commission exercises this power, it must pay the reasonable value of their services, including a profit, to those persons found by the Commission to have performed services in the discovery, mining, and extraction of the metal. It does not have to pay for the uranium or thorium.

Up to the present time, the Commission has not thought it desirable or necessary to exercise either of these rights, and it will not be the policy of the Commission to exercise them except in case of emergency where no other course of action is practicable. It is not expected that such an occasion is likely to arise.

In preference to exercising its right of entry or its power to require delivery, the Commission follows the policy of acquiring ores or concentrates through ordinary commercial means. Accordingly, the guaranteed minimum prices established by the Commission apply to ores removed from claims located on the public lands after August 1, 1946.

EXECUTIVE ORDERS

Three Executive orders have been issued by the President since September 13, 1945, which affect the rights to uranium or thorium of persons who staked certain claims or who now lease or own certain classes of land formerly owned by the Government. Most prospectors and miners will not be affected by the provision of these Executive orders. The claims and lands which are affected are described below:

Claims Staked Between September 13, 1945, and July 30, 1946

On September 13, 1945, by Executive Order No. 9613, the President withdrew from entry all vacant and unappropriated public lands which contained deposits of radioactive mineral substances. On March 4, 1946, by Executive Order No. 9701, these lands were generally reopened for entry under the nonmineral land laws, but entries under the mining laws were still not permitted until the effective date of the Atomic Energy Act, August 1, 1946, which qualified the terms of Executive Order No. 9701. As a result, no valid mining location could be staked on public lands containing uranium or thorium ores from September

13, 1945, through midnight, July 30, 1946, except in some cases where the amount of uranium or thorium was not substantial. Inquiries as to the validity of an individual claim believed to have been located between September 13, 1945 and July 30, 1946, should be addressed to the Bureau of Land Management, Department of the Interior, Washington 25, D. C.

Public Lands Leased Between March 4 and July 30, 1946

Public lands containing substantial amounts of uranium or thorium were subject to lease under the leasing laws during the period between March 4 and July 30, 1946, but all mineral leases issued were required by Executive Order No. 9701 to contain a reservation to the United States of all uranium or thorium deposits in the land, and a right in the Government to enter, prospect for, mine, and remove these deposits.

Government-Owned Lands Other Than Public Lands Leased or Purchased Between September 13, 1945, and December 4, 1947

From September 13, 1945, through March 3, 1946, Government-owned lands other than public lands (known usually as acquired lands) generally could not be sold, because of Executive Order 9613, then in force, if they contained deposits of uranium or thorium ores. Leases of Government-owned lands, other than public lands, made during that time were required to contain a reservation of the right of the United States to enter on the lands and mine and remove the uranium or thorium deposits of the leased lands.

From March 4, 1946, through December 4, 1947, sales or leases of Government-owned lands other than public lands were permitted, but the person purchasing or leasing these lands generally received no rights in any uranium or thorium deposits contained in the lands sold or leased, and the Government reserved the right to enter and remove deposits. Inquiries relating to Government-owned lands other than public lands sold or leased from September 13, 1945, through December 4, 1947, should be addressed to the agency which sold or leased the property.

LAWS AND REGULATIONS APPLYING TO PROSPECTING

Government-Owned Lands Other Than Public Lands Leased or Purchased Since December 5, 1947

Under Executive Order No. 9908 the present owner (or lease-holder) of Government-owned lands other than public lands sold by the Government after December 5, 1947, has the same rights to uranium or thorium deposits on his land as a locator who has staked a claim on public land after August 1, 1946, unless the lands were sold or leased subject to a reservation of all minerals. In other words, the uranium in these lands may be worked or leased in the same way as any other mineral deposits, and the ores removed may be sold or transferred to licensed buyers

or delivered to the Atomic Energy Commission for its guaranteed minimum prices. As in the case of claims located on public lands, the Government reserves the right to enter and mine the ore, or to require delivery if it deems this to be necessary. These rights, however, do not apply to certain plots of less than 1 acre which are devoted primarily to residential use.

Inquiries arising in connection with formerly Government-owned lands other than public lands leased or purchased since December 5, 1947, should be addressed to the agency which sold or leased the property or to the U. S. Atomic Energy Commission, Washington 25, D. C.

UNITED STATES DEPARTMENT OF THE INTERIOR, BUREAU OF LAND MANAGEMENT

Circular No. 1278

INFORMATION IN REGARD TO MINING CLAIMS ON THE PUBLIC DOMAIN

The purpose of this circular is to furnish brief information pertinent to the location and purchase of mining claims under the United States mining laws.

1. *Initiation of rights to mineral land.* Rights to mineral lands, owned by the United States, are initiated by prospecting for minerals thereon, and, upon the discovery of mineral, by locating the lands upon which such discovery has been made. A location is made by staking the corners of the claim, posting notice of location thereon (see 10), and complying with the State laws, regarding the recording of the location in the county recorder's office, discovery work, etc.

2. *State mining laws.* As supplemental to the United States mining laws there are State statutes relative to location, manner of recording of mining claims, etc., in the State, which should also be observed in the location of mining claims. Information as to State laws can be obtained locally or from State officials.

3. *Lands subject to location and purchase.* Vacant public surveyed or unsurveyed lands are open to prospecting, and upon discovery of mineral, to location and

purchase, as are also lands in national forests in the public-land States (forest regulations must be observed), lands entered or patented under the stock raising homestead law (title to minerals only can be acquired), lands entered under other agricultural laws but not perfected, where prospecting can be done peaceably, and lands within the railroad grants for which patents have not issued.

4. *Status of lands.* Information as to whether any particular tract of land is shown by the records to be vacant and open to prospecting may be obtained from the manager of the land district in which the tract is situated. Since location notices of mining claims are filed in the office of the county recorder, ordinarily no information regarding unpatented mining claims is obtainable from the district land office or the Bureau of Land Management unless application for patent has been filed.

5. *Minerals subject to location.* Whatever is recognized as a mineral by the standard authorities, whether metallic or other substance, when found in public lands in quantity and quality sufficient to render the lands valuable on account thereof, is treated as coming within the purview of the mining laws. Deposits of coal, oil, gas, oil shale, sodium, phosphate, potash, and in Louisiana and New Mexico

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sulphur, belonging to the United States, can be acquired under the mineral leasing laws, and are not subject to location and purchase under the United States mining laws.

6. *Mining locations—Areas.* Lode locations for minerals discovered in lode or vein formation may not exceed in length 1,500 feet along the vein and in width 300 feet on each side of the middle of the vein, the end lines of the location to be parallel to each other. Placer locations, which include all minerals not occurring in vein or lode formation, may be for areas of not more than 20 acres for each locator, no claim to exceed 160 acres made by not less than eight locators. Placer locations must conform to the public surveys wherever practicable.

7. *Who may make locations.* Citizens of the United States, or those who have declared their intention to become such, including minors who have reached the age of discretion and corporations organized under the laws of any State. Agents may make locations for qualified locators.

8. *Number of locations.* The United States mining laws do not limit the number of locations that can be made by an individual or association.

9. *Valid locations—Discovery after conveyance.* A location is not valid until an actual discovery of mineral is made within the limits thereof. A placer location of more than 20 acres, made by two or more locators and conveyed to a less number before discovery is made, is valid to the extent of 20 acres only for each owner at date of discovery.

10. *Locations to be marked on ground—Notice.* Except placer claims described by legal subdivision, all mining claims must be distinctly marked on the ground so that their boundaries may be readily traced, and all notices must contain the name or names of the locators, the date of location and such a description of the claim by reference to some natural object or permanent monument as will serve to identify the claim.

11. *Locations on streams and bodies of water.* Beds of navigable waters are subject to the laws of the State in which they are situated and are not locatable under the United States mining laws. Title to the beds of meandered nonnavigable streams is in the riparian owner. The beds of un-

meandered, nonnavigable streams are subject to location under the United States mining laws if they are unoccupied, as are also the beds of meandered nonnavigable streams when the abutting upland is unappropriated.

12. *Maintenance—Annual assessment work—Adverse claim—Jurisdiction.* The right of possession to a valid mining claim is maintained by the expenditure annually of at least \$100 in labor or improvements of a mining nature on the claim, the first annual assessment period commencing at 12 o'clock noon on the 1st day of July succeeding the date of location. Failure to perform the assessment work for any year will subject the claim to relocation, unless work for the benefit of the claim is resumed before a relocation is made. The determination of the question of the right of possession between rival or adverse claimants to the same mineral land is committed exclusively to the court. (See 18.) However, failure to perform the annual assessment work on a mining claim in Alaska works a forfeiture of the claim, and resumption of work on the claim will not prevent relocation.

13. *Expenditures on claim for patent purposes—Lode—Placer—Mill site.* Five hundred dollars in labor or improvements of a mining nature, must be expended upon or for the benefit of each lode or placer claim, and compliance with the United States mining laws made otherwise, to entitle the claimant to prosecute patent proceedings therefor. Such expenditures must be completed prior to the expiration of the period during which notice of the patent proceedings is published. Patent expenditures on a mill site are not required, but it must be shown that the mill site is used or occupied for mining or milling purposes at the time an application for patent therefor is filed.

14. *Patent not necessary.* One may develop, mine, and dispose of mineral in a valid mining location without obtaining a patent, but possessory right must be maintained by the performance of annual assessment work on the claim in order to prevent its relocation by another.

15. *Procedure to obtain patent to mining claims.* The owner or owners of a valid mining location, or group of locations, on

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which not less than \$500 has been expended on or for the benefit of each claim, may institute patent proceedings therefor in the district land office. Information as to patent procedure can be obtained from the manager of the local land office or from the Bureau of Land Management. In general, a survey must be applied for unless the claim is a placer claim located by legal subdivisions, the application for survey to be made to the public survey office in the State wherein the claim is situated. Applications for patent are filed in the district land office. A notice of the application is required to be posted on the land prior to filling the application and to be published by the register after the application is filed.

16. *Blank forms.* No set form of location notices nor of the papers filed in patent proceedings for mining claims is required and no blank forms are furnished by the Bureau of Land Management or by the district land offices, for use in mineral cases. Forms containing essentials are printed by local private parties or concerns. The managers of the local land offices can usually advise you where such forms may be obtained.

17. *Common improvements.* An improvement, made upon one of a group of contiguous claims (cornering is not contiguity) owned in common, may be applied to such claims of the group, in existence at the time the improvement is made, shown to be benefited thereby.

18. *Adverse claims.* An adverse claim may be filed during the period of publication of notice of an application for patent (or within 8 months after the expiration of the publication period in Alaska), by one claiming a possessory right under another mining location to all or some portion of the land applied for, and must show fully the nature, boundaries, and extent of the area in conflict, to be followed, within 30 days after filing (60 days in Alaska), by suit in a court of competent jurisdiction. If suit is filed, all proceedings on the application, except the filing of the affidavits of continuous posting and publication of the notice of the application, are stayed to await the outcome of the court proceedings.

19. *Coowners.* A coowner not named in the application for patent cannot assert his rights by filing an adverse claim, a protest being proper to cause his alleged rights

to be considered when the case is adjudicated. If a coowner fails to do his proper proportion of annual assessment work on a claim, or fails to contribute his proportion of the cost thereof, the coowners who have caused the work to be done during any assessment period may, at the expiration of the assessment year, give such delinquent coowner personal notice in writing, or notice by publication in a newspaper published nearest the claim for at least once a week for 90 days, and if at the expiration of 90 days after such notice in writing, or 180 days after the first newspaper publication, such delinquent should fail to contribute his proportion of the expense required, his interest in the claim becomes the property of his coowners who have made the expenditure.

20. *Lode in placer.* If a placer mining applicant fails to state that there is a known lode within the boundaries of the claim, it is taken as a conclusive declaration that he has no right of possession thereto. If no such vein or lode be known the placer patent will convey all valuable mineral and other deposits within the boundaries of the claim. A known lode not included in an application for patent to the claim may be applied for even after issuance of patent to the placer mining claim. Where a placer mining claimant makes application for a placer containing within its boundaries a lode claim owned by him the lode must be surveyed, the lode being paid for on the basis of \$5 per acre and the remaining portions of the placer at the rate of \$2.50 per acre.

21. *The United States mining laws are applicable to the following States:* Arizona, Arkansas, California, Colorado, Florida, Idaho, Louisiana, Mississippi, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oregon, South Dakota, Utah, Washington, and Wyoming; also in the Territory of Alaska.

22. *National parks and monuments:* With the exception of Mount McKinley National Park and Glacial Bay National Monument in Alaska, Organ Pipe Cactus National Monument in Arizona, and Death Valley National Monument in California, mining locations may not be made on lands in national parks and monuments after their establishment.

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23. *Withdrawals.* Withdrawals usually bar location under the mining laws, but withdrawals made under the act of June 25, 1910 (36 Stat. 847), as amended by the act of August 24, 1912 (37 Stat. 497), permit locations of the withdrawn lands containing metaliferous minerals. Lands withdrawn for water power purposes are not subject to location unless first restored under the provisions of section 24 of the Federal Water Power Act.

24. *Minerals in Indian lands.* In general, the mineral deposits in Indian reservations are subject to leasing and are under the administration of the Office of Indian Affairs.

25. *Mineral land in agricultural entries—Protest—Contest.* Where lands known to be valuable for minerals are embraced in an agricultural filing, other than a stock raising homestead filing, a mineral claimant may initiate a contest thereagainst by filing a protest sworn to and in duplicate, in the local land office, alleging sufficient facts, which, if proven, will establish the mineral

character of the land, and warrant cancellation of the agricultural filing. The protest must be corroborated by one or more witnesses having knowledge of the facts alleged. In the case of stock raising homestead entries, a mineral claimant, whose location antedates the homestead filing, must protest such filing in order to protect his title to the surface of his mining claim.

26. *Cost of patent proceedings for mining claims.* With the exception of the fixed charges, such as the fee for filing an application for patent, which is \$10, the purchase price of lands in lode claims and millsites at \$5 per acre, and \$5 for each fractional part of an acre, and \$2.50 per acre or fraction of an acre for placer lands, unless otherwise provided by law as to certain lands, no estimate can be furnished as to what it will cost to procure a patent. The cost of publication, survey, and abstract of title depends upon the services rendered and vary in each case.

FRED W. JOHNSON,
Director.

LAWS AND SPECIAL ORDERS*

Atomic Energy Act of 1946 (Public Law 585—79th Congress)

PROVISIONS AFFECTING SOURCE MATERIALS

Sec. 5 (b) SOURCE MATERIALS.

(1) *DEFINITION.* As used in this Act, the term "source material" means uranium, thorium, or any other material, which is determined by the Commission, with the approval of the President, to be peculiarly essential to the production of fissionable materials; but includes ores only if they contain one or more of the foregoing materials in such concentration as the Commission may by regulation determine from time to time.

(2) *LICENSE FOR TRANSFERS REQUIRED.* Unless authorized by a license issued by the Commission, no person may transfer or deliver, receive possession of or title to, or export from the United States any source

material after removal from its place of deposit in nature, except that licenses shall not be required for quantities of source materials which, in the opinion of the Commission, are unimportant.

(3) *ISSUANCE OF LICENSES.* The Commission shall establish such standards for the issuance, refusal, or revocation of licenses as it may deem necessary to assure adequate source materials for production, research, or development activities pursuant to this Act or to prevent the use of such materials in a manner inconsistent with the national welfare. Licenses shall be issued in accordance with such procedures as the Commission may by regulation establish.

(4) *REPORTING.* The Commission is authorized to issue such regulations or orders requiring reports of ownership, possession, extraction, refining, shipment, or other handling of source materials as it may deem

* From *Prospecting for Uranium*, published by the U. S. Atomic Energy Commission and the U. S. Geological Survey, U. S. Government Printing Office, Washington, D. C., 1951.

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necessary, except that such reports shall not be required with respect to (A) any source material prior to removal from its place of deposit in nature, or (B) quantities of source materials which in the opinion of the Commission are unimportant or the reporting of which will discourage independent prospecting for new deposits.

(5) ACQUISITION. The Commission is authorized and directed to purchase, take, requisition, condemn, or otherwise acquire, supplies of source materials or any interest in real property containing deposits of source materials to the extent it deems necessary to effectuate the provisions of this Act. Any purchase made under this paragraph may be made without regard to the provisions of section 3709 of the Revised Statutes (U. S. C., title 41, sec. 5) upon certification by the Commission that such action is necessary in the interest of the common defense and security, or upon a showing that advertising is not reasonably practicable, and partial and advance payments may be made thereunder. The Commission may establish guaranteed prices for all source materials delivered to it within a specified time. Just compensation shall be made for any property taken, requisitioned, or condemned under this paragraph.

(6) EXPLORATION. The Commission is authorized to conduct and enter into contracts for the conduct of exploratory operations, investigations, and inspections to determine the location, extent, mode of occurrence, use, or conditions of deposits or supplies of source materials, making just compensation for any damage or injury occasioned thereby. Such exploratory operations may be conducted only with the consent of the owner, but such investigations and inspections may be conducted with or without such consent.

(7) PUBLIC LANDS. All uranium, thorium, and all other materials determined pursuant to paragraph (1) of this subsection to be peculiarly essential to the production of fissionable material, contained, in whatever concentration, in deposits in the public lands are hereby reserved for the use of the United States subject to valid claims, rights, or privileges existing on the date of the enactment of this Act: *Provided, however*, That no individual, corporation, partnership, or association, which had any part, directly or indirectly, in the development

of the atomic bomb project, may benefit by any location, entry, or settlement upon the public domain made after such individual, corporation, partnership, or association took part in such project, if such individual, corporation, partnership, or association, by reason of having had such part in the development of the atomic bomb project, acquired, confidential official information as to the existence of deposits of such uranium, thorium, or other materials in the specific lands upon which such locations, entry, or settlement is made, and subsequent to the date of the enactment of this Act made such location, entry, or settlement or caused the same to be made for his, its, or their benefit. The Secretary of the Interior shall cause to be inserted in every patent, conveyance, lease, permit, or other authorization hereafter granted to use the public lands or their mineral resources, under any of which there might result the extraction of any materials so reserved, a reservation to the United States of all such materials, whether or not of commercial value, together with the right of the United States through its authorized agents or representatives at any time to enter upon the land and prospect for, mine, and remove the same, making just compensation for any damage or injury occasioned thereby. Any lands so patented, conveyed, leased, or otherwise disposed of may be used, and any rights under any such permit or authorization may be exercised, as if no reservation of such materials had been made under this subsection; except that, when such use results in the extraction of any such material from the land in quantities which may not be transferred or delivered without a license under this subsection, such material shall be the property of the Commission and the Commission may require delivery of such material to it by any possessor thereof after such material has been separated as such from the ores in which it was contained. If the Commission requires the delivery of such material to it, it shall pay to the person mining or extracting the same, or to such other person as the Commission determines to be entitled thereto, such sums, including profits, as the Commission deems fair and reasonable for the discovery, mining, development, production, extraction, and other

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services performed with respect to such material prior to such delivery, but such payment shall not include any amount on account of the value of such material before removal from its place of deposit in nature. If the Commission does not require delivery of such material to it, the reservation made pursuant to this paragraph shall be of no further force or effect.

Executive Order 9908

RESERVATION OF SOURCE MATERIAL IN CERTAIN LANDS OWNED BY THE UNITED STATES

By virtue of the authority vested in me as President of the United States, and in further effectuation of the policies declared by section 1 of the Atomic Energy Act of 1946 (60 Stat. 755), it is hereby ordered as follows:

1. So far as not in conflict with existing law, (a) all disposals of lands, other than public lands heretofore or hereafter acquired by the United States or any instrumentality thereof, including lands in the Territories and possessions of the United States, except in conveyances where all minerals, including source material, are reserved to the United States; (b) all leases, permits, or other authorizations of whatever kind hereafter granted to remove minerals from such lands; and (c) all leases, permits, or other authorizations which otherwise would preclude the United States from exercising its right to enter upon the lands and prospect for, mine, and remove minerals, shall contain the following reservation:

"All uranium, thorium, and all other materials determined pursuant to section 5 (b) (1) of the Atomic Energy Act of 1946 (60 Stat. 761) to be peculiarly essential to the production of fissionable material, contained, in whatever concentration, in deposits in the lands covered by this instrument are hereby reserved for the use of the United States, together with the right of the United States through its authorized agents or representatives at any time to enter upon the land and prospect for, mine, and remove the same, making just compensation for any damage or injury occasioned

thereby. However, such land may be used, and any rights otherwise acquired by this disposition may be exercised, as if no reservation of such materials had been made; except that when such use results in the extraction of any such material from the land in quantities which may not be transferred or delivered without a license under the Atomic Energy Act of 1946, as it now exists or may hereafter be amended, such material shall be the property of the United States Atomic Energy Commission, and the Commission may require delivery of such material to it by any possessor thereof after such material has been separated as such from the ores in which it was contained. If the Commission requires the delivery of such material to it, it shall pay to the person mining or extracting the same, or to such other person as the Commission determines to be entitled thereto, such sums, including profits, as the Commission deems fair and reasonable for the discovery, mining, development, production, extraction, and other services performed with respect to such material prior to such delivery, but such payment shall not include any amount on account of the value of such material before removal from its place of deposit in nature. If the Commission does not require delivery of such material to it, the reservation hereby made shall be of no further force or effect."

2. The reservation required by paragraph 1 above need not be included in any disposition of land which is not in excess of one acre and which is devoted primarily to a residential use.

3. Executive Order No. 9701 of March 4, 1946, entitled "Providing for the Reservation of Rights to Fissionable Materials in Lands Owned by the United States," is hereby revoked; but such revocation shall not be construed to affect the revocation of Executive Order No. 9613 made by Executive Order No. 9701 or the provisions contained therein with respect to the lands released from withdrawal by the revocation of Executive Order No. 9613.

HARRY S. TRUMAN.

THE WHITE HOUSE,
December 5, 1947

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UNITED STATES ATOMIC ENERGY COMMISSION LICENSING REGULATIONS

GENERAL PROVISIONS

§ 40.1 *Basis and purpose.* The regulations in this part, for the control of source material essential to the production of fissionable material, are promulgated by the United States Atomic Energy Commission pursuant to the Atomic Energy Act of 1946 (60 Stat. 755) in order to assure adequate source material for production, research, and development activities and to prevent the use of such material in a manner inconsistent with the national welfare.

§ 40.2 *Definitions.* (a) As used in this part, the term "source material" means any material, except fissionable material, which contains by weight one-twentieth of one per cent (0.05%) or more of (1) uranium, (2) thorium, or (3) any combination thereof.

(b) "Fissionable material" means fissionable material as defined in section 5 of the Atomic Energy Act of 1946 and regulations which may be issued pursuant to that act by the Commission.

(c) "Raw source material" means (1) source material which has not been chemically processed in any manner and (2) source material in the form of residues or tailings.

(d) "Refined source material" means source material other than raw source material.

(e) "Person" means any individual, corporation, partnership firm, association, trust, estate, public or private institution, group, the United States or any agency thereof, any government other than the United States, any political subdivision of any such government, and any legal successor, representative, agent, or agency of the foregoing, or other entity, but shall not include the Commission or officers or employees of the Commission in the exercise of duly authorized functions.

(f) "The United States," when used in a geographical sense, includes all territories and possessions of the United States and the Canal Zone.

(g) "Commission" means the Atomic Energy Commission created by the Atomic Energy Act of 1946, or its duly authorized representative.

TRANSFER OF SOURCE MATERIAL

§ 40.10 *Restriction on transfers.* Unless authorized by a license issued by the Commission, no person may transfer or deliver, receive possession of or title to, or export from the United States, any source material after removal from its place of deposit in nature. This includes the disposition of raw source material (including residues or tailings) by dumping into streams or sewers, or disposition in such other manner that recovery cannot be made. The restriction of this section does not apply to any transfer, delivery, or receipt of possession or title exempted by § 40.11.

§ 40.11 *Exempted transfers.* Except where export is intended or where export occurs, the restriction of § 40.10 does not apply to any transfer, delivery, or receipt of possession or title, of the following:

(a) During any single calendar month a quantity of raw source material after removal from its place of deposit in nature which contains less than 10 pounds of uranium or thorium or any combination thereof, or

(b) Products listed in Schedule I (§ 40.60).

LICENSES

§ 40.20 *Applications for licenses.* Applications for licenses to transfer or deliver, receive possession of or title to, or export source material shall be filed with the United States Atomic Energy Commission, Washington 25, D. C., Attention: Licensing Controls Branch. Applications should be filed on Form AEC-2, copies of which are available at the above address. When it is impracticable to use this form, applications may be made by letter or telegram, giving the information required by Form AEC-2.

§ 40.21 *Issuance of licenses.* Upon a determination that an application meets the requirements of the Atomic Energy Act of 1946 and of the regulations of the Commission, the Commission will issue a license in such form and upon such conditions as it deems appropriate and in accordance with law.

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§ 40.22 *Standards for issuance of licenses.*

In making the determination mentioned in § 40.21, the Commission will be guided by the following standards:

(a) Assurance of the common defense and security;

(b) Assurance of adequate source materials for production, research and development;

(c) Prevention of the use of source materials in a manner inconsistent with the national welfare;

(d) Preservation of health and safety.

So far as consistent with these standards, licenses will be granted upon conditions that will not interfere with the conduct of normal business activities. No license will be issued to any person if to do so would, in the opinion of the Commission, be inimical to the common defense and security.

§ 40.23 *Types of licenses.* Licenses are of two basic types, general and specific. General licenses are issued to an identified class of persons who are not designated by name, such as common or contract carriers, retail druggists or physicians, and others, to permit transfers of source material under specified conditions without the filing of an application with the Commission. General licenses now in effect are set out in Schedule III (§ 40.62). Specific licenses are issued to named persons in response to applications filed with the Commission. Specific licenses may authorize a continuing activity or, as in the case of exports, may be limited to an individual transaction. So far as consistent with the purposes of the Atomic Energy Act of 1946, licenses will be tailored to fit the normal business requirements of the licensee.

§ 40.24 *Conditions of licenses.* Each license will require the licensee to comply with certain conditions, including the filing of reports with the Commission and restrictions upon the use of source material. Willful failure of a licensee to file any such report which truthfully sets forth all information required, or willful failure to comply with any other condition of the license, shall constitute a violation of the regulations in this part.

§ 40.25 *Revocation, suspension, modification of licenses.* Any license may be modified, withdrawn, suspended, revoked, or annulled at any time in the discretion of

the Commission upon a determination by the Commission that the public health, interest or safety requires such action or that the licensee has willfully failed to comply with any condition of the license. In the absence of such a determination, no modification, withdrawal, suspension, revocation, or annulment of any license will be made except upon application therefor by the licensee or unless, prior thereto, facts or conduct warranting such action have been called to the attention of the licensee in writing and the licensee has been accorded opportunity to demonstrate or achieve compliance with all lawful requirements. Nothing in this part shall limit the authority of the Commission to issue or amend its regulations in accordance with law.

§ 40.26 *Renewal of licenses.* In any case in which a licensee has filed an application in proper form for a renewal or a new license not less than 30 days prior to expiration of his existing license, such existing license, to the extent that it has reference to any activity of a continuing nature, shall not expire until the application for a renewal or a new license has been finally determined by the Commission.

§ 40.27 *Transfer of licenses.* Licenses shall be nontransferable.

§ 40.28 *Licenses to transfer uranium for certain uses.* Unless justified by exceptional circumstances licenses will not be issued for transfers of source material which contains by weight uranium in excess of one-twentieth of one percent (0.05%) for use in the manufacture of or for incorporation in any of the products listed in Schedule II (§ 40.61).

§ 40.29 *Control or possession of source material by persons who do not hold specific or general licenses.* (a) Any person who has, or who hereafter obtains, possession of or title to (1) a quantity of raw source material after removal from its place of deposit in nature which contains 10 pounds or more of uranium, thorium, or any combination thereof, or (2) a quantity of refined source material which contains 1 pound or more of uranium, thorium, or any combination thereof (except refined source material imported in products listed in Schedule I (§ 40.60)) shall, not later than 30 days after the effective date of the regulations in this part or after the date of obtaining such

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possession or title, whichever is later, file with the Commission a reasonably detailed statement of:

- (i) The nature of the material,
- (ii) Its quantity,
- (iii) Its uranium and thorium content,
- (iv) Its location, and
- (v) Its ownership.

(b) The requirement in paragraph (a) of this section does not apply to any person who holds a specific or general license from the Commission.

REPORTS

§ 40.30 *Reports.* Reports, in addition to those called for in licenses, may be required by the Commission from time to time, subject to approval by the Bureau of the Budget in certain cases, with respect to the ownership, possession, extraction, refining, shipment, or other handling of source material after removal from its place of deposit in nature, as the Commission may deem necessary.

NOTE: The reporting requirements hereof have been approved by the Bureau of the Budget pursuant to the Federal Reports Act of 1942.

VIOLATIONS

§ 40.40 *Penalties for violations.* A violation of the regulations in this part shall be deemed to be a violation of the Atomic Energy Act of 1946 and shall subject the violator to the penalties therein prescribed. In addition, the Commission may take such action with respect to source material involved in any violation as it deems appropriate and in accordance with law.

INTERPRETATIONS, PETITIONS, AND COMMUNICATIONS

§ 40.50 *Valid interpretations.* Except as specifically authorized by the Commission, no interpretation or explanation of the meaning of the regulations in this part issued by any officer or employee of the Commission other than one issued by the General Counsel in writing will be recognized to be valid and binding upon the Commission.

§ 40.51 *Petitions.* Petitions for relief from any restriction imposed under the regulations in this part may be made by filing a letter, in duplicate, with the United States Atomic Energy Commission, Washington

25, D. C., Attention: Licensing Controls Branch, stating the reasons why the petition should be granted.

§ 40.52 *Communications.* All communications concerning the regulations of this part or any license issued under them should be addressed to the United States Atomic Energy Commission, Washington 25, D. C., Attention: Licensing Controls Branch.

§ 40.53 *Right to Require Deliveries Reserved.* No license granted under the regulations in this part shall be deemed to constitute a waiver of the Commission's right to require delivery of source material to it under the conditions stated in Section 5(b) (7) of the Atomic Energy Act of 1946 (60 Stat. 755).

SCHEDULES

§ 40.60 *Schedule I: Exempted products* (see § 40.10 and § 40.29).

- (a) Incandescent mantles.
- (b) Ceramic products.
- (c) Refractories.
- (d) Glass products.
- (e) Photographic film, negatives and prints.

(f) Rare earth metals and compounds, mixtures and products containing not more than 0.25% by weight thorium, uranium, or any combination of these.

(g) Vacuum tubes.

(h) Thoriated tungsten containing not more than 3% by weight thorium.

§ 40.61 *Schedule II: Prohibited uses of uranium* (see § 40.28).

- (a) Ceramic products.
- (b) Glass products.
- (c) Photographic film, negatives, and prints.

§ 40.62 *Schedule III: General licenses* (see § 40.23). Transfers, deliveries and receipts of possession of or title to source material, except where export is intended or where export occurs, which are within any one or more of the following categories, are hereby generally licensed:

(a) Transfers, deliveries and receipts of possession of (but not title to) source material by contractors and agents of the Commission, or its subcontractors in any tier, in the authorized course of their business for the Commission;

Public Law 585 Enacted On August 13, 1954, too late to be included in this book, the President signed Public Law 585, 83rd Congress, amending the mineral laws to provide for multiple mineral development of the same tracts of the public lands. As a result of the new law the Commission is terminating Domestic Uranium Program Circular 7, as of December 12, 1954, which provided for the issuance of leases to make public lands, affected by the mineral leasing laws and closed to mineral entry under the mining laws, available for uranium mining purposes. With the passage of Public Law 585, it is now possible to establish mining locations on these lands and the need for the issuance of leases under Circular 7 no longer exists and no further leases will be issued. Under the new law, holders of uranium leases or lease applications under Circular 7 have the prior right during the 120-day period following the enactment of the law—or until December 12, 1954, in which to locate mining claims on the land covered by their lease or lease application. Holders of leases under Circular 7 may also elect to continue to hold their lease, but in general, such leases will not be extended beyond the initial 5-year period. The law also repealed the provision of the Atomic Energy Act of 1946 reserving uranium on public lands to the United States.

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AEC Circular No. 7

URANIUM LEASES ON LANDS AFFECTED BY FEDERAL MINERAL LEASING LAWS

§ 60.7 *Uranium leases on lands affected by Federal mineral leasing laws*—(a) *What this section does.* This section provides for the issuance of leases by the United States Atomic Energy Commission to make certain public lands available for uranium mining purposes. It is designed to encourage the search for, development and production of uranium-bearing ores. It is intended to apply to public lands which at the time of leasing for uranium are not subject to location of mining claims under the United States mining laws because such lands are embraced within an offer, application, permit, or lease under the Mineral Leasing Act of 1920 (41 Stat. 437; 30 U. S. C. 181 et seq.), as amended, or because such lands are known to be valuable for minerals leaseable under that act.

(b) *Statutory authority.* The Atomic Energy Act of 1946, as amended (60 Stat. 755-775; 67 Stat. 240; 42 U. S. C. 1801-1819) is authority for this section.

(c) *Procedure for acquiring a lease.* (1) The lands as to which a lease is sought must be in tracts, preferably rectangular, not to exceed 1,500 feet in length by 600 feet in width, which must be distinctly identified and marked on the ground by suitable monuments at each corner so that the surface boundaries thereof may be readily found and traced. When the true point for a tract corner falls upon an inaccessible place, a witness corner should be established. Monuments should be posts not less than 4 inches in diameter or stone monuments at least 18 inches high and must be marked with the name of the tract and the designation of the corner, either by number or cardinal point.

(2) There must be posted conspicuously at one of the corner monuments for each tract of land so marked, a written or printed "Notice of Lease Application" containing the name(s) of the applicant(s), the name of the tract, the date of posting, the length and general course of the boundary lines of the tract and the position of the tract referenced to a corner of the public land survey or, if there is no public land survey, a natural object or permanent monument.

(3) The applicant or applicants shall record the "Notice of Lease Application" for each tract in the office of the county recorder of the county in which such tract is situated within thirty days after the identification, marking and posting of such tract on the ground as provided for in subparagraphs (1) and (2) of this paragraph.

(4) An application for a lease provided for by this section must be filed with the Atomic Energy Commission, Grand Junction Operations Office, P. O. Box 270, Grand Junction, Colorado, on a form prescribed for this purpose, within sixty days after the recordation required by subparagraph (3) of this paragraph, and must be accompanied by a certified copy or copies of the recorded "Notice of Lease Application," the rental required by paragraph (f) of this section, and a map satisfactory to the Commission on which one inch equals 500 feet or less, showing (i) land subdivision if surveyed, (ii) tract pattern with courses and distances of the boundary lines, and reference to a corner of the public land survey, if surveyed, or reference to a natural object or permanent monument, if unsurveyed, by which the location of the tract(s) on the ground can be readily and accurately ascertained, and (iii) position of conflicting claims of which the applicant or applicants are aware. The Commission may require additional information in connection with consideration of the application.

(d) *Eligibility of applicants.* Uranium mining leases under this section will be issued only to qualified applicants who are (1) citizens of the United States, (2) associations of such citizens, or (3) corporations organized under the laws of the United States or of any state or territory thereof. A uranium mining lease will not be issued to anyone under 21 years of age.

(e) *Commission decisions.* All matters connected with issuance and administration of leases will be determined by the Commission, using the provisions of this section as criteria. Although priority in posting a tract, provided there is timely compliance with the other provisions of paragraph (c) of this section, will normally be the controlling criterion in cases where more than one application has been filed for part or all of a particular tract, consideration may

be given to other factors. The Commission reserves the right to refuse to issue a lease as to any or all the tracts included in an application even though there has been compliance with the terms of this section if it believes such refusal is desirable in the national interest.

NOTE: Misrepresentation or falsification of facts in a notice of application for lease or in the application may subject the offender to criminal penalties under pertinent provisions of the United States Code including section 1001 of Title 18. Any such offenses also will disqualify the offender from receiving a lease.

(f) *Royalty and rentals.* Leases under this section will be on a royalty-free basis. Rental shall be ten dollars (\$10) per lease year per tract of 1,500 feet by 600 feet, or fraction thereof, payable in advance by certified check or money order made payable to Treasurer of United States, at the time of application for a lease and prior to the beginning of each lease year thereafter. No refund of rental will be made by the Commission to the lessee or lessees should the lease be relinquished or canceled as provided for in paragraphs (k) and (l) of this section. If an insufficient rental payment is made, the Commission may, at its discretion, select the tracts under the lease to which the payment is applicable.

(g) *Work requirements.* A condition of every lease entered into under this section will be the conduct on the leased premises of exploration, development or mining activities with reasonable diligence, skill and care for the purpose of achieving and maintaining maximum production of uranium ore consistent with good mining practice and the size of the deposit, unless other arrangements are specified in writing by the Commission. In any event, but not in limitation of the lease condition set forth in the preceding sentence, such activities must include for each 1,500 feet by 600 feet tract, or fraction thereof constituting a tract, one hundred dollars (\$100) worth of labor performed or improvements made on or beneath the surface of the leased premises during each lease year. Labor performed or expenditures made in marking or posting the tract or tracts comprising the leased premises, expenditures attributable to travel of personnel to and from the premises and acquisition cost of equipment

may not be applied to satisfy work requirements of the lease. A statement signed by the lessee or lessees must be submitted to the Commission within fifteen (15) days after the close of each lease year listing the work performed under the lease as measured in lineal feet of each type of drilling, cubic yards of surface excavation in rock, gravel, earth or other material, cubic feet of underground excavation, indicated by type, or other work performed or improvements made on the leased premises. Whenever cost of labor is used as a measure of work performed, the statement must include the name or names of the workmen performing the labor, date or dates on which work was performed and a description of the work performed. In determining the cost of labor, actual wage rates shall be used unless they are in excess of rates prevailing in the area for similar work at the time the work was done, in which case the prevailing rates shall be used for the purposes of this computation. Labor performed or improvements made on any one tract may be applied to not more than nine (9) additional contiguous tracts under the same lease in the order designated by the lessees. Labor performed or improvements made under one lease may not be applied to satisfy work requirements under any other lease issued under this section.

(h) *Size of lease.* Ordinarily no lease containing in excess of 100 tracts will be issued.

(i) *Lands to be in a reasonably compact body.* The area covered by a lease under this section should be in a reasonably compact body and will ordinarily consist of adjoining tracts or tracts closely situated to each other. No lease under this section shall convey extra-lateral rights.

(j) *Term of lease.* A lease issued under this section ordinarily will be for a term of five (5) years and renewable as to any or all of the tracts for not more than five (5) additional periods of three (3) years each upon written application made by a lessee or lessees in good standing within sixty (60) days prior to expiration of the lease or any extension thereof. If a tract leased under this section becomes open in whole or in part to location of mining claims under the United States mining laws during the lease term, the Commission may refrain from thereafter extending such lease as to the land so opened to such entry.

LAWS AND REGULATIONS APPLYING TO PROSPECTING

(k) *Relinquishment.* A lease or any of the tracts under a lease may be relinquished by the lessee or lessees by written notification sent to the Commission at its Grand Junction, Colorado, office. Relinquishment shall take effect on the date such notification is received by the Commission as evidenced by the written acknowledgement of the Commission. The lessee or lessees within fifteen (15) days of receipt of the Commission's acknowledgement of relinquishment shall file the acknowledgement in the office of the county recorder for the county in which such leased tracts are located.

(l) *Cancellation.* Should the lessee or lessees fail to comply with any of the terms and conditions of the lease within thirty (30) days after receipt of written notice from the Commission specifying such failure and requesting compliance, or should there be any falsification or misrepresentation of a material fact, whether or not intentional, in the notice of lease application or in the application for uranium mining lease, the Commission shall have the right to terminate such lease in whole or in part and the Commission shall then be entitled and authorized to take immediate possession of the affected land and dispossess all persons occupying the same under the authority of the lease.

(m) *Effective date of lease.* A lease issued under this section will ordinarily be effective as of the date it is signed by the Commission.

(n) *Assignment.* Leases issued under this section may be assigned as to all or any of the leased tracts subject to approval by the Commission. To procure such approval, all instruments of transfer of the lease must be filed at the Commission's Grand Junction, Colorado, office and must contain all of the terms and conditions agreed upon by the parties thereto. The application for approval of assignment must be accompanied by a statement of the assignee or assignees setting forth his or their qualifications to hold a lease and that he or they accept and agree to be bound by the terms and conditions of the lease, provided the assignment is approved by the Commission. No assignment of a lease will be approved which provides for royalties on uranium-bearing ore production from the leased premises which amount to more than fifteen percent (15%) of gross ore receipts, or

which when added to royalties already created to more than fifteen percent (15%) of gross ore receipts. In calculating gross ore receipts for the purpose of this paragraph, development and haulage allowances payable pursuant to § 60.5 (Commission's Domestic Uranium Program Circular 5, Revised) or any further revision thereof or equivalent allowances will be first excluded. With the approval of the Commission, less than all the tracts described in the lease may be assigned. In such an event the Commission may require the execution of a new lease by the assignor or assignee or both. The Commission will not grant approval if it determines that the terms and conditions of the proposed assignment do not embody terms and conditions equivalent to those of the original lease to the extent applicable. After the effective date of approval, the assignee or assignees will be responsible for the performance of all such obligations.

(o) *Designation of representative.* When leases are issued or assigned under this section to a group of two or more persons or legal entities, they shall designate one person to represent them for the receipt of communications or notices or to make reports or statements on their behalf, together with the address of the representative. This designation shall be binding on the lessees until the Commission has received notice in writing from the lessees of a new designee and his address.

(p) *Initial production bonus.* The provisions of § 60.6 (Domestic Uranium Program Circular 6) shall be applicable to ores produced from the leased premises.

(q) *Form of lease.* Leases will be issued on forms prescribed by the Atomic Energy Commission.

(r) *Recording of lease.* The holder or holders of a lease or assignment under this section shall, unless otherwise authorized by the Commission, record the lease or assignment within fifteen (15) days of the date thereof in the office wherein the "Notice of Lease Application," required by paragraph (c) (3) of this section is recorded.

(s) *Withdrawn lands.* Lands withdrawn from mineral entry by the Secretary of the Interior for the use of the Atomic Energy Commission or embraced within an Atomic

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Energy Commission application for such land withdrawal are not available for leasing under this section. However, tracts situated on lands not open to location of mining claims under the United States mining laws because of the existence of a lease, permit, application, or offer under the Mineral Leasing Act of 1920 as amended, or because such lands are known to be valuable for minerals leasable under that act, which lands are subsequently withdrawn by the Secretary of the Interior and reserved for the use of the Atomic Energy Commission, or included in an application for withdrawal filed by the Commission, will be eligible for this type of lease provided that such tracts have been identified and marked on the ground and the "Notice of Lease Application" posted and recorded as required by paragraph (c) of this section, prior to the effective date of the withdrawal or segregation, and further provided there is compliance with the other provisions of this section.

(t) *Multiple use of lands.* Leases issued under this section will also provide that operations under them will be conducted in

such manner as not to interfere with the lawful operations of any third party having a lease, permit, easement or any other right or interest in the premises.

(u) *Reservation of rights.* The right is reserved by the Commission to revise, modify or terminate the regulations in this section at any time without prejudice to rights of leaseholders established under existing leases.

(v) *Definitions as used in this section.*

(1) "Commission" means the Atomic Energy Commission created by the Atomic Energy Act of 1946, or its duly authorized representative.

(2) "Lease Year" shall be the annual period commencing on the date of the lease or any anniversary thereof during the lease term.

(60 Stat. 755-775, 67 Stat. 240; 42 U. S. C. 1801-1819)

Dated at Washington, D. C., this 29th day of January 1954.

By order of the Commission.

K. D. NICHOLS,
General Manager.

Appendix X—Location of Mining Claims in Nine Western States

ARIZONA

Uranium claims are staked in the same manner as lode claims. The Arizona Code, Annotated, 1939, requires as follows:

Section 65-101. *Location upon discovery of mineral in place.* On the discovery of mineral in place on the public domain of the United States the same may be located as a mining claim by the discoverer for himself, or for himself and others, or for others. [R.S. 1901, Sec. 3231; 1913, Sec. 4027; R.C. 1928, Sec. 2266.]

Section 65-102. *Location notice, contents—Amendment.* Such location shall be made by erecting at or contiguous to the point of discovery a conspicuous monument of stones, not less than three (3) feet in height, or an upright post, securely fixed, projecting at least four (4) feet above the ground, in or on which there shall be posted a location notice, signed by the name of the locator. The location notice must con-

tain: The name of the claim located; the name of the locator; the date of the location; the length and width of the claim in feet, and the distance in feet from the point of discovery to each end of the claim; the general course of the claim; the locality of the claim with reference to some natural object or permanent monument whereby the claim can be identified; and until each of the same shall have been done no right to such location shall be acquired. The notices may be amended at any time and the monuments changed to correspond with the amended location; provided, that no change shall be made which will interfere with the rights of others. [R.S. 1901, Secs. 3232, 3233, 3238; 1913, Secs. 4028, 4029, 4034; cons. & rev., R.C. 1928, Sec. 2267.]

Section 65-103. *Completing location—Additional acts—Failure.* From the time of the location the locator shall be allowed ninety

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(90) days within which to do the following: Cause to be recorded in the office of the county recorder a copy of the location notice; sink a discovery shaft in the claim to a depth of at least eight (8) feet from the lowest part of the rim of the shaft at the surface, and deeper, if necessary, until there is disclosed in said shaft mineral in place; and monument the claim on the ground so that its boundaries can be readily traced. Failure to do all such things in the time and place specified shall be an abandonment of the claim, and all right and claim thereto of the discoverer and locator shall be forfeited. [R.S. 1901, Secs. 3234, 3235; Laws 1909, ch. 60, Sec. 1, p. 157; 1913, Secs. 4030, 4031; cons. & rev., R.C. 1928, Sec. 2268.]

Section 65-104. *Monumenting.* Such boundaries shall be monumented by six (6) substantial posts projecting at least four (4) feet above the surface of the ground, or by substantial stone monuments at least three (3) feet high, one at each corner of the said claim and one at the center of each end line thereof; when, however, the point of a monument is at the same point and coincides with a monument of the survey of the United States, the monument of such government survey, shall be deemed a mining claim monument. [R.S. 1901, Sec. 3236; 1913, Sec. 4032; Laws 1919, ch. 125, Sec. 1, p. 196; rev., R.C. 1928, Sec. 2269.]

Section 65-105. *Tunnel as location work.* Any open cut, adit or tunnel, made as a part of the location of a lode mining claim, equal in amount of work to a shaft eight (8) feet deep and four (4) feet wide by six (6) feet long, and which shall cut a lode or mineral in place at a depth of ten (10) feet from the surface, shall be equivalent, as discovery work, to a shaft sunk from the surface. [R.S. 1901, Sec. 3237; Laws 1909, ch. 60, Sec. 2, p. 157; R.S. 1913, Sec. 4033; rev., R.C. 1928, Sec. 2270.]

Section 65-106. *Relocation.* The location of an abandoned or forfeited claim shall be made in the same manner as other locations, except that the relocater may perform his location work by sinking the original location shaft eight (8) feet deeper than it was originally, or if the original location work consisted of a tunnel or open cut, he may perform his location work by extending said tunnel or open cut by removing therefrom two hundred and forty (240)

cubic feet of rock or vein material. [R.S. 1901, Sec. 3241; Laws 1907, ch. 22, Sec. 1, p. 27; R.S. 1913, Sec. 4037, in part; R.C. 1928, Sec. 2271.]

Section 65-108. *Affidavit of performance of annual work—Prima facie evidence.* Within three (3) months after the expiration of the time fixed for the performance of annual labor or the making of improvements upon a mining claim, the person on whose behalf such work or improvement was made, or some person for him knowing the facts, may make and record an affidavit, in substance as follows:

State of Arizona, county of _____ ss: _____, being duly sworn, deposes and says that he is a citizen of the United States and more than twenty-one years of age, resides at _____, in _____ county, Arizona, is personally acquainted with the mining claim known as _____ mining claim, situated in _____ mining district, Arizona, the location notice of which is recorded in the office of the county recorder of said county, in book _____ of records of mines, at page _____. That between the _____ day of _____, A.D. _____, and the _____ day of _____, A.D. _____, at least _____ dollars worth of work and improvements were done and performed upon said claim, not including the location work of said claim. Such work and improvements were made by and at the expense of _____, owners of said claim, for the purpose of complying with the laws of the United States pertaining to assessment or annual work, and (here name the miners or men who worked upon the claim in doing the work) were the men employed by said owner and who labored upon said claim, did said work and improvements, the same being as follows, to wit: (here describe the work done, and add signature and verification).

Such affidavit when recorded, shall be prima facie evidence of the performance of such labor or improvements. [R.S. 1901, Sec. 3240, 3241, in part; Laws 1907, ch. 22, Sec. 1, p. 27; R.S. 1913, Sec. 4035, 4037, in part; cons. & rev., R.C. 1928, Sec. 2273.]

Section 65-109. *One affidavit for group.* When two (2) or more contiguous claims are owned by the same person, and constitute a group, and the annual work is done upon each of said claims or upon one (1) or more of the same for the benefit of

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all, or wholly or partly outside of such claims for the benefit of all, all such claims may be included in a single affidavit. [R.S. 1913, Sec. 4036; R.C. 1928, Sec. 2274.]

Section 65-112. *Sufficiency of description of mining claims.* In all actions, judgments, grants or conveyances it shall be a sufficient

description of a mining claim if the name of the claim, the district, county and state where it is situated, and the book and page where the location notice thereof is recorded can be intelligently learned therefrom. [R.S. 1901, Sec. 3249; 1913, Sec. 4046; rev., R.C. 1928, Sec. 2277.]

CALIFORNIA

Uranium claims are staked in the same manner as lode claims. The California Code* requires as follows:

Section 2301. *Location of lode claim; Persons entitled to locate; Posting of notice; Contents of notice.* Any person, a citizen of the United States, or who has declared his intention to become a citizen, who discovers a vein or lode of quartz, or other rock in place, bearing gold, silver, cinnabar, lead, tin, copper, or other valuable deposit, may locate a claim upon such vein or lode, by defining the boundaries of the claim, in the manner hereinafter described, and by posting a notice of such location, at the point of discovery. The notice shall contain:

(a) The name of the lode or claim.

(b) The name of the locator or locators.

(c) The number of linear feet claimed in length along the course of the vein, each way from the point of discovery, with the width on each side of the center of the claim, and the general course of the vein or lode, as near as may be.

(d) The date of location.

(e) Such a description of the claim by reference to some natural object, or permanent monument, as will identify the claim located.

Section 2302. *Same; Definition of boundaries; Maximum dimensions; Erection of monuments.* The locator or locators of any lode mining claim shall define the boundaries of the claim so that they may be readily traced, but in no case shall the claim extend more than fifteen hundred feet along the course of the vein or lode, nor more than three hundred feet on either side thereof as measured from the center line of the vein at the surface. Within sixty days after the date of location of any lode mining claim hereafter located, the locator or locators shall erect at each corner of the claim and at the center of each end

line, or the nearest accessible points thereto, a post not less than four inches in diameter, or a stone monument at least eighteen inches high.

Section 2304. *Improvement of claims; Excavation of shaft, tunnel or open cut.*

(a) Within 90 days after the date of location of any lode mining or placer claim hereafter located, the locator or locators thereof shall sink a discovery shaft upon the claim to a depth of at least 10 feet from the lowest part of the rim of the shaft at the surface, or shall drive a tunnel, adit, or open cut upon the claim to at least 10 feet below the surface.

(b) In lieu of the discovery work required by paragraph (a) of this section, the locator of a placer mining claim may, within 90 days of the date of location, excavate an open cut upon the claim, removing from the cut not less than seven cubic yards of material.

Section 2306. *Relocation of claims; Improvements required; Options.* The relocation of any lode or placer mining location which is subject to relocation shall be made as an original location is required to be made, except that the relocater may either sink a new shaft upon the ground relocated to a depth of at least 10 feet from the lowest part of the rim of the shaft at the surface, or drive a new tunnel, adit, or open cut upon the ground to at least 10 feet below the surface; or the relocater may sink the original discovery shaft 10 feet deeper than it is at the time of relocation, or drive the original tunnel, adit, or open cut upon the claim 10 feet farther or, in the case of placer mining claims, relocater may either excavate a new open cut upon the claim, removing from the cut not less than seven cubic yards of material, or remove from the original cut not less than seven additional cubic yards of material.

* Public Resources Code of the State of California, Chapter 4.

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Section 2307. *Effect of failure to comply with statute; Suspension of right of relocation.* The failure or neglect of the locator or locators to comply with the requirements of sections 2301, 2302, 2304, 2305 or 2306 of this code shall render the location null and void, and no portion of the area within the location shall be subject to relocation by the same locator or locators within the period of three years from the date of the void location.

Section 2310. *Validation of defective locations; Filing of amended notice; Effect of amendment.* If at any time the locator of any mining claim, or his assigns, apprehends that his original location notice was defective, erroneous, or that the requirements of the law had not been complied with before filing, or in case the original notice was made prior to the passage of this chapter, and he is desirous of securing the benefit of this chapter, such locator, or his assigns, may file an amended notice, subject to the provisions of this chapter, if such amended location notice does not interfere with the existing rights of others at the time of posting and filing the amended location notice. No amended location notice or the record thereof shall preclude the claimant or claimants from proving any such title as he or they may have held under previous locations.

Section 2313. *Recordation of copy of notice of location; Accompanying statements; Recorder's fee.* Within 90 days after the posting of his notice of location upon a lode mining claim, placer claim, tunnel right or location, or mill site claim or location, the locator shall record a true copy of the notice, together with a statement of the markings of the boundaries as required in this chapter, and of the performance of the discovery work, in the office of the county recorder of the county in which such claim is situated. The county recorder shall receive a fee of one dollar for this service. [As amended: Chap. 644, Stats. 1941.]

Section 2314. *Amount of work necessary to hold claim.* The amount of work done or improvements made during each year to hold possession of a mining claim shall be that prescribed by the laws of the United States, to wit: One hundred dollars annually.

Section 2315. *Affidavit of performance of work, etc.; Contents of affidavit; Filing; Evidentiary effect.* Whenever a mine owner has performed the labor and made the improvements required by law upon any mining claim, the person in whose behalf such labor was performed or improvements made, or someone in his behalf shall, within thirty days after the time limited for performing such labor or making such improvements, make and have recorded by the county recorder, in books kept for that purpose, in the county in which the mining claim is situated, an affidavit setting forth the value of labor or improvements, the name of the claim, and the name of the owner or claimant of the claim at whose expense the labor was performed or the improvements were made. The affidavit, or a copy thereof, duly certified by the county recorder, shall be prima facie evidence of the performance of such labor or the making of such improvements, or both.

Section 2321. *Effect of failure to perform required work; Suspension of right of relocation.* The failure or neglect of any locator of a mining claim to perform development work of the character, in the manner, and within the time required by the laws of the United States shall disqualify such locator from relocating the ground embraced in the original location or mining claim or any part thereof under the mining laws, within three years after the date of his original location, and any attempted relocation thereof by any of the original locators shall render such location void.

COLORADO

Uranium claims are staked in the same manner as lode claims. The Colorado Code requires as follows:

1935 Colorado Statutes Annotated, Chapter 110, Part II, Article 1, Section 168—*Length of lode claim.* The length of any

lode claim hereafter located may equal but not exceed fifteen hundred feet along the vein.

Section 169. *Width of lode claim.* The width of all lode claims hereafter located may equal, but shall not exceed three hun-

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dred feet on each side of the middle of the vein or crevice, and the owner or owners of any lode claim or claims heretofore located and having a less width, desirous of securing the benefit of this section may file an additional certificate claiming such additional width as herein provided; provided, however, that such additional certificate does not interfere with the existing rights of others at the time of filing of the same, and no such additional certificate or other record thereof shall preclude the claimant or claimants from proving such titles as he or they have held under previous location.

Section 170. *Three months to record location certificate—Contents.* The discoverer of a lode shall, within three months from the date of discovery, record his claim in the office of the recorder of the county in which such lode is situated, by a location certificate which shall contain:

First—The name of the lode.

Second—The name of the locator.

Third—The date of location.

Fourth—The number of feet in length claimed on each side of the center of discovery shaft.

Fifth—The general course of the lode as near as may be.

Section 171. *When location certificate void.* Any location certificate of a lode claim which shall not contain the name of the lode, the name of the locator, the date of location, the number of lineal feet claimed on each side of the discovery shaft, the general course of the lode, and such description as shall identify the claim with reasonable certainty, shall be void.

Section 172. *Certificate shall contain but one location.* No location certificate shall claim more than one location, whether the location be made by one or several locators. And if it purport to claim more than one location it shall be absolutely void, except as to the first location therein described, and if they are described together, or so that it cannot be told which location is first described, the certificate shall be void as to all.

Section 173. *Manner of locating claims.* Before filing such location certificate the discoverer shall locate his claim by:

First—Sinking a discovery shaft upon the lode to the depth of at least ten feet from the lowest part of the rim of such shaft at the surface, or deeper, if necessary

to show a well defined crevice.

Second—By posting at the point of discovery on the surface a plain sign or notice, containing the name of the lode, the name of the locator, and the date of discovery.

Third—By marking the surface boundaries of the claim.

Section 174. *Marking boundaries—Posts—Piles of stones.* Such surface boundaries shall be marked by six substantial posts hewed or marked on the side or sides which are in toward the claim, and sunk in the ground, to wit: one at each corner and one at the center of each side line. Where it is practically impossible on account of bed rock to sink such posts, they may be placed in a pile of stones, and where in marking the surface boundaries of a claim any one or more of such posts shall fall by right upon precipitous ground, where the proper placing of it is impractical or dangerous to life or limb, it shall be legal and valid to place any such post at the nearest practicable point, suitably marked, to designate the proper place.

Section 175. *Open cross-cut—Tunnel—Adit—To hold lode.* Any open cut, cross-cut or tunnel which shall cut a lode at the depth of ten feet below the surface, shall hold such lode, the same as if a discovery shaft were sunk thereon, or an adit of at least ten feet in along the lode from the point where the lode may be in any manner discovered, shall be equivalent to a discovery shaft.

Section 176. *Sixty days to sink discovery shaft.* The discoverer shall have sixty days from the time of uncovering or disclosing a lode to sink a discovery shaft thereon.

Section 177. *What location includes—Extra lateral rights.* The location or location certificate of any lode claim shall be construed to include all surface ground within the surface lines thereof, and all lodes and ledges throughout their entire depth, the top or apex of which lie inside of such lines extended downward, vertically, with such parts of all lodes or ledges as continue by dip beyond the side lines of the claim, but shall not include any portion of such lodes or ledges beyond the end lines of the claim or the end lines continued, whether by dip or otherwise, or beyond the side lines in any other manner than by the dip of the lode.

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MONTANA

Uranium claims are staked in the same manner as lode claims. The Revised Codes of Montana, 1947, require as follows:

Section 50-701. (7365) *Discovery—Notice—Marking boundaries—Sinking shaft.* Any person who discovers upon the public domain of the United States, within the State of Montana, a vein, lode, or ledge of rock in place, bearing gold, silver, cinnabar, lead, tin, copper, or other valuable deposits, or a placer deposit of gold, or other deposit of minerals having a commercial value which is subject to entry and patent under the mining laws of the United States, may, if qualified by the laws of the United States, locate a mining claim upon such vein, lode, ledge, or deposit in the following manner, viz.:

1. He shall post, conspicuously, at the point of discovery, a written or printed notice of location, containing the name of the claim, the name of the locator (or locators, if there be more than one), the date of the location, which shall be the date of posting such notice, and the approximate dimensions of area of the claim intended to be appropriated.

2. Within thirty days after posting the notice of location, he shall distinctly mark the location on the ground so that its boundaries can be readily traced. It shall be prima facie evidence that the location is properly marked if the boundaries are defined by a monument at each corner or angle of the claim, consisting of any one of the following kinds:

(1) A tree at least eight inches in diameter, and blazed on four sides:

(2) A post at least four inches square by four feet six inches in length, set one foot in the ground, unless solid rock should occur at a less depth, in which case the post should be set upon such rock, and surrounded in all cases by a mound of earth or stone at least four feet in diameter by two feet in height. A squared stump of the requisite size, surrounded by such mound, shall be deemed the equivalent of a post and mound;

(3) A stone at least six inches square by eighteen inches in length, set two-thirds of its length in the ground, with a mound of earth or stone

alongside at least four feet in diameter by two feet in height; or

(4) A boulder at least three feet above the natural surface of the ground on the upper side. Where other monuments, or monuments of lesser dimensions than those above described, are used, it shall be a question for the jury, or for the court where the action is tried without a jury, as to whether the location has been marked upon the ground so that its boundaries can be readily traced. Whatever monument is used, it must be marked with the name of the claim and the designation of the corner, either by number or cardinal point.

3. Within sixty days after posting such notice, he shall sink a shaft upon the vein, lode, or deposit, at or near the point of discovery, to be known as the discovery shaft. Such shaft shall be sunk to the depth of at least ten feet, vertically, below the lowest part of the rim of such shaft at the surface, or deeper if necessary to disclose the vein or deposit located, and the cubical contents of such shaft shall be not less than one hundred and fifty cubic feet; provided, that any cut or tunnel which discloses the vein, lode, or deposit, located at a vertical depth of at least ten feet below the natural surface of the ground, and which constitutes at least one hundred and fifty feet of excavation, shall be deemed the equivalent of such shaft; and provided also, that where the vein, lode, or deposit located is disclosed at a less vertical depth than ten feet, any deficiency in the depth of the discovery shaft, cut, or tunnel may be compensated for by any horizontal extension of such working, or by any excavation done elsewhere upon the claim, equaling, in cubical contents, the cubical extent of such deficiency; but in every case at least seventy-five cubic feet of excavation shall be made at the point of discovery.

Section 50-702. (7366) *Record of certificate of location.* Within sixty days after posting the notice of location, and for the purpose of constituting constructive notice of the location, the locator shall record his location in the office of the county clerk of the county in which such mining claim is situated. Such record shall consist of a certificate of location containing:

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1. The name of the lode or claim.
2. The name of the locator or locators, if there be more than one.

3. The date of location, and such description of said claim, with reference to some natural object or permanent monument, as will identify the claim.

4. In the case of a lode claim, the direction and distance claimed along the course of the vein each way from the discovery shaft, cut, or tunnel, with the width claimed on each side of the center of the vein.

5. In the case of a placer claim, the dimensions or area of the claim, and the location thereon on the discovery shaft, cut, or tunnel.

6. The locator and claimant, at his option, may also set forth, in such certificate of location, a description of the discovery work, the corner monuments, and the markings thereon, and any other facts showing a compliance with the provisions of this law. Such certificate of location must be verified, before some officer authorized to administer oaths, by the locator, or one of the locators if there be more than one, or by authorized agent. In the case of a corporation, the verification may be made by any officer thereof, or by an authorized agent. When the verification is made by an agent, the fact of the agency shall be stated in the affidavit. A certificate of location so verified, or a certified copy thereof, is prima facie evidence of all facts properly recited therein.

Section 50-704. (7368) *Recording of affidavit of performance of annual work.* The owner of a lode or placer claim who performs or causes to be performed the annual work, or makes the improvements required by the laws of the United States in order to prevent the forfeiture of the claim, may, within twenty days after the annual work, file in the office of the county clerk of the county in which such claim is situated an affidavit of his own, or an affidavit of the person who performed such work or made the improvements, showing:

1. The name of the mining claim, and where situated;
2. The number of days' work done, and the character and value of the improvements placed thereon;

3. The date of performing such work, and of making the improvements;

4. At whose instance the work was done or the improvements made;

5. The actual amount paid for work and improvements, and by whom paid when the same was not done by the owner.

Such affidavits, or a certified copy thereof, are prima facie evidence of the facts therein stated.

Section 50-706. (7370) *Relocation of abandoned claim.* The relocater of an abandoned or forfeited mining claim may adopt as his discovery any shaft or other working, existing upon such claim at the date of the relocation, in which the vein, lode, or deposit is disclosed, but, in such shaft or other working, he shall perform the same discovery work as is required in the case of an original location.

Section 50-707. (7371) *Rights of relocater.* The rights of a relocater of any abandoned or forfeited mining claim, hereafter located, shall date from the posting of his notice of location thereon, and while he is duly performing the acts required by law to perfect his location, his rights shall not be affected by any re-entry or resumption of work by the former locator or claimant.

Section 50-708. (7372) *Amended location.* A locator or claimant may at any time amend his location, and make any change in the boundaries which does not involve a change in the point of discovery as shown by the discovery shaft, by marking the location as amended upon the ground, and filing an amended certificate of location conforming to the requirements of an original certificate of location. A defect in a recorded certificate of location may be cured by filing an amended certificate.

Section 50-709. (7373) *Relocation by owner.* A locator or claimant may at any time relocate his own claim for any purpose, except to avoid the performance of annual labor thereon, and, by such relocation, may change the boundaries of his claim, or the point of discovery, or both, but such relocation must comply in all respects with the requirements of this law as to an original location.

Section 50-710. (7374) *Amendment or relocation not a waiver of acquired rights.* Where a locator or claimant amends or re-

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locates his own claim, such amendment or relocation shall not be construed as a waiver of any right or title acquired by him by virtue of the previous location or record thereof, except as to such portions of the previous location as may be omitted from the boundaries of the claim as amended or relocated. As to the portion of ground included both in the original location and the locations as amended or relocated, he may rely either upon the original location or the location as amended or relocated, or upon both; provided, that nothing herein contained shall be construed as permitting the locator or claimant to hold a tract which does not include a valid discovery.

Section 50-713. (7377) *Defective locations good against persons with notice.* The period of time prescribed by this law for the performance of any act shall not be deemed mandatory where the act is performed before the rights of third persons have intervened, and no defect in the posted notice or recorded certificate shall be deemed material, except as against one who has located the same ground, or some portion thereof in good faith and without notice. Notice to an agent, who makes a location in behalf of another, shall be deemed notice to his principal, and notice

to one of several coclaimants shall be deemed notice to all.

Section 50-715. (7379) *Amended locations.* If at any time the locator of any mining claim heretofore or hereafter located, or his successors or assigns, shall apprehend that his original declaratory statement was defective or erroneous, or that the requirements of law had not been complied with, or shall be desirous of changing his boundaries, or taking in any part of an overlapping claim which has been abandoned, or in case his original declaratory statement was filed prior to the passage of this law and he shall be desirous of securing the benefit of this act, such locator, or his successors or assigns, may file an additional or amended declaratory statement subject to the provisions of this act; provided, that such relocation or filing of the amended or additional declaratory statement shall not interfere with the existing rights of others at the time of such relocation or filing of the amended or additional declaratory statement, or other record thereof, shall preclude the claimant or claimants from proving any such title as he or they may have held under the previous location and notice thereof.

NEVADA

Uranium claims are staked in the same manner as lode claims. The Nevada Code* requires as follows:

Section 4120. *Who may locate—Method—Form and posting of notice.* Any person who is a citizen of the United States, or who has declared his intention to become such, who discovers a vein or lode, may locate lode mining claim thereon by defining the boundaries of the claim in the manner and within the time hereinafter prescribed, and by erecting or constructing at the point of such discovery a monument of the size and character of any of the several monuments prescribed in Section 2 of this Act and by posting in or upon such discovery monument a notice of such location, which must contain:

First—the name of the claim.

Second—the name of the locator or locators, together with the post office address of such locator or locators.

Third—the date of location.

Fourth—the number of linear feet claimed in the length along the course of the vein, each way from the point of discovery, with the width claimed on each side of the center of the vein and the general course of the lode or vein, as near as may be.

Section 4121. *Location work—Boundaries, how and when defined.* Section 2—The locator of the lode mining claim must sink a discovery shaft upon the claim located four feet by six feet to the depth of at least ten feet from the lowest part of the rim of such shaft at the surface, or deeper, if necessary to show by such work a lode deposit of mineral in place;

* Nevada Compiled Laws, 1929.

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a cut or crosscut or tunnel which cuts a lode at a depth of ten feet or an open cut along the said ledge or lode, equivalent in size to a shaft four feet by six feet by ten feet deep, is equivalent to a discovery shaft. The locator must define the boundaries of his claim by removing the top of a tree (having a diameter of not less than four inches) not less than three feet above the ground, and blazing and marking the same, or by a rock in place, capping such rock with smaller stones, such rock and stones to have a height of not less than three feet, or by setting a post or stone one at each corner and one at the center of each side line. When a post is used, it must be at least four inches in diameter by four and one-half feet in length set one foot in the ground. When it is practically impossible, on account of bedrock or precipitous ground, to sink such posts, they may be placed in a mound of earth or stones, or where the proper placing of such posts or other monuments is impracticable or dangerous to life or limb, it shall be lawful to place such posts or monuments at the nearest point properly marked to designate its right place. When a stone is used (not a rock in place) it must be not less than six inches in diameter and eighteen inches in length set two-thirds of its length in the top of a mound of earth or stone, four feet in diameter and two and one-half feet in height. All trees, posts or rocks used as monuments, when not four feet in diameter at the base, shall be surrounded by a mound of earth or stone four feet in diameter by two feet in height, which trees, posts, stones or rock monuments must be so marked as to designate the corners of the claim located; *provided however*, that the locator of a mining claim shall within twenty days from the date of posting the notice of location define the boundaries of said claim by placing at each corner and at the center of each side line one of the hereinbefore described monuments, and shall within ninety days of the date of posting said location notice perform the location work hereinbefore prescribed. As amended, Stats. 1899, 93; 1901, 97; 1907, 419.

Section 4123. *What location includes.* Section 4—The location or record of any vein or lode claim shall be construed to include all surface ground within the sur-

face lines thereof, and all lodes and ledges throughout their entire depth, the top or apex of which lies inside of such lines extended downward, vertically with all parts of such lodes or veins as continue to dip beyond the side lines of the claim, but shall not include any portion of such lodes, veins, or ledges beyond the end lines of the claim, or the end lines continued, whether by dip or otherwise, or beyond the side lines in any other manner than by the dip of the lode.

Section 4124. *Lode not to be followed beyond end lines.* Section 5—If the top or apex of the lode in its longitudinal course extends beyond the exterior lines of the claim at any point on the surface, or as extended vertically downward, such lode may not be followed in its longitudinal course where it is intersected by the exterior lines.

Section 4125. *Defective and additional certificate—Change of boundaries—Existing Rights.* Section 6—If at any time the locator of any mining claim heretofore or hereafter located, or his assigns, shall apprehend that his original certificate was defective, erroneous, or that the requirements of the law had not been complied with before filing; or shall be desirous of changing his surface boundaries or of taking in any part of an overlapping claim which has been abandoned; or in case the original certificate was made prior to the passage of this law, and he shall be desirous of securing the benefits of this act, such locator or his assigns may file an additional certificate, subject to the provisions of this act; *provided*, that such relocation does not interfere with the existing rights of others at the time of such relocation, and no such relocation or the record thereof shall preclude the claimant or claimants from proving any such titles as he or they may have held under previous location.

Section 4126. *Relocation—Work to be done—New boundaries—Record.* Section 7—The relocation of abandoned lode claims shall be by sinking a new discovery shaft and fixing new boundaries in the same manner as if it were the location of a new claim; or the relocater may sink the original discovery shaft ten feet deeper than it was at the time of abandonment, in which case the record must give the

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depth and dimensions of the original discovery shaft at the date of such relocation, and erect new or adopt the old boundaries, renewing the posts or monuments if removed or destroyed. In either case a new location stake shall be erected. In any case, whether the whole or part of an abandoned claim is taken the record may state that the whole or any part of the new location is located on abandoned property. If it is not known to the relocater that his location is on an abandoned claim, then the provisions of this section do not apply.

Section 4129. *Affidavit of work performed—Record—Evidence.* Section 10—Within sixty days after the performance of labor or making of improvements, required by law to be annually performed or made upon any mining claim, the person in whose behalf such labor was performed, or improvements made, or someone in his behalf, shall make and have recorded by the mining district recorder or the county recorder in books kept for that purpose in the mining district or the county in which such mining claim is situated, an affidavit setting forth the amount of money expended, or value of labor or improvements, a description of the claim or part of the claim affected by such expenditures, or labor or improvements, for what year, and the name of the owner or claimant of said claim at whose expense the same was made or performed. Such affidavits or a copy thereof, duly certified by the county recorder, shall be prima facie evidence of the performance of such labor or the making of such improvements or both.

Section 4131. *Notice to claim but one location.* Section 12—No notice of location of a lode claim shall claim more than one location, whether the location be made by one or several persons. And if such notice purport to claim more than one location it shall be absolutely void, except as to the first location therein described. And if they are described together, or so that it cannot be told which location is first described, the notice of location shall be void as to all.

Section 4143. *Certificate of location and labor need not be sworn to.* Section 24—Certificates of location and of labor and improvements necessary to hold claims need

not be sworn to, and are not required to be in any specified form, nor to state facts in any specific order; but must truly state the required facts.

Section 4144. *Recording of locations when no district recorder.* Section 25—Where there is no mining district, or where a district having once existed the residence of the officers within the district and their places of business within the district where the books are kept are not publicly known, district recording shall not be required of the locator or claim owner. But recording shall be required in the office of the county recorder in all cases; as well where there is a district recorder as where there is none.

Section 4122. *Location notice, filing and contents—Record of location—Contents of location certificate—Former records validated.* Section 3—Any locator or locators of a mining claim, after having established the boundaries of said claims, and after having complied with the provisions of this act with reference to the establishment of such boundaries, may file with the district mining recorder a notice of location, setting forth the name given to the lode or vein, the number of linear feet claimed in length along the course of the vein, the date of location, the date on which the boundaries of the claim were completed, and the name of the locator or locators. Should any claim be located in any section or territory where no district has been as yet formed, or where there is no district recorder, the locator or locators of such claims may file with the county recorder, notice of location as set forth above, and said notice of location will be prima facie evidence in all courts of justice of the first location of said lode or vein. Within ninety days of the date of posting the location notice upon the claim of locator (he) must record his claim with the county recorder of the mining district or county in which such claim is situated by location certificate which must contain:

First—the name of the lode or vein;

Second—the name of the locator or locators, together with the post office address of such locator or locators;

Third—the date of the location and such description of the location of said claim, with reference to some natural object or

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permanent monument, as will identify the claim;

Fourth—the number of linear feet claimed in length along the course of the vein each way from the point of discovery with the width on each side of the center of the vein, and the general course of the lode or vein as near as may be;

Fifth—the dimensions and locations of the discovery shaft or its equivalent, sunk upon the claim;

Sixth—the location and description of each corner, with the markings thereon. Any record of the location of a lode mining claim which shall not contain all the requirements named in this section shall be void, and every location of a mining claim made after the effective date hereof

shall be absolutely void unless a certificate of location thereof substantially complying with the above requirements is recorded with the county recorder of the county in which the claim is located within ninety days after the date of location. All records of lode or placer mining claims, millsites, or tunnel rights heretofore made by any recorder of any mining district or any county recorder are hereby declared to be valid and to have the same force and effect as records made in pursuance of the provisions of this Act. And any such record, or a copy thereof duly verified by a mining recorder or duly certified by a county recorder, shall be prima facie evidence of the facts therein stated.

NEW MEXICO

Uranium claims are staked in the same manner as lode claims. The New Mexico Statutes, 1941, require as follows:

Section 67-201. *Mining claim—Location—Posting notice—Record in office of county clerk.* Any person or persons desiring to locate a mining claim upon a vein or lode of quartz or other rock in place bearing gold, silver, cinnabar, lead, tin, copper or other valuable deposit, must distinctly mark the location on the ground so that its boundaries may be readily traced, and post in some conspicuous place on such location, a notice in writing stating thereon the name or names of the locator or locators, his or their intention to locate the mining claim, giving a description thereof by reference to some natural object or permanent monument as will identify the claims; and also within three (3) months after posting such notice, cause to be recorded a copy thereof in the office of the clerk of the county in which the notice is posted. And provided, no other record of such notice shall be necessary. [Laws 1876, ch. 38, Sec. 1; C. L. 1884, Sec. 1566; C. L. 1897, Sec. 2286; Code 1915, Sec. 3445; C. S. 1929, Sec. 88-101.]

Section 67-203. *Discovery shaft—Requirements.* The locator or locators of any mining claim, located after this act shall take effect, shall, within ninety (90) days from the date of taking possession of the same, sink a discovery shaft upon such claim, to a depth of at least ten (10) feet from the

lowest part of the rim of such shaft at the surface, exposing mineral in place, or shall drive a tunnel, adit, or open cut upon such claim, to at least ten (10) feet below the surface, exposing mineral in place. [Laws 1889, ch. 25, Sec. 1; C. L. 1897, Sec. 2298; Code 1915, Sec. 3447; C. S. 1929, Sec. 88-103.]

Section 67-204. *Boundary posts.* The surface boundaries of mining claims hereafter located shall be marked by four (4) substantial posts or monuments, one (1) at each corner of such claim, so as to distinctly mark the claim on the ground, so that its boundaries can be readily traced, and shall otherwise conform to section 3445 [Section 67-201]. [Laws 1889, ch. 25, Sec. 2; 1897, ch. 58, Sec. 6; C. L. 1897, Sec. 2299; Laws 1899, ch. 57, Sec. 1; Code 1915, Sec. 3448; C. S. 1929, Sec. 88-104.]

Section 67-205. *Relocation—New discovery shaft—Deepening shaft, tunnel or adit.* The relocation of any mining ground, which is subject to relocation, shall be made in the same way as an original location is required by law to be made, except the relocater may either sink a new shaft upon the ground relocated to the depth of at least ten (10) feet from the lowest part of the rim of such shaft at the surface, exposing mineral in place, or drive a new tunnel, adit, or open cut upon such ground, at least ten (10) feet below the surface, exposing mineral in place, or the relocater may sink the original discovery shaft ten

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(10) feet deeper than it is at the time of relocation, or drive the original tunnel, adit, or open cut upon such claim, ten (10) feet farther. [Laws 1889, ch. 25, Sec. 3; C. L. 1897, Sec. 2300; Code 1915, Sec. 3449; C. S. 1929, Sec. 88-105.]

Section 67-206. *Amended and additional location notices.* If at any time the owner of any mining claim heretofore or hereafter located, or his assigns, shall apprehend that the original notice of location is defective, erroneous or the requirement of law has not been complied with before filing; or shall be desirous of changing his surface boundaries or to take in any part of an over-lapping claim which has been abandoned, such owner may file in the office where notices of location are by law required to be filed, an amended or additional notice of location, subject to the provisions of this article. Provided, that such additional or amended notice of location does not interfere with the existing right of others at the time of filing such notice; and no such amended or additional location, or record thereof, shall preclude the claimant or his assigns from proving any such title as he or they may have held under the previous location. [Laws 1889,

ch. 25, Sec. 4; C. L. 1897, Sec. 2301; Code 1915, Sec. 3450; C. S. 1929, Sec. 88-106.]

Section 67-211. *Affidavit as prima facie evidence of assessment work—Failure to file.* The owner or owners of any unpatented mining claim in this state, located under the laws of the United States and of this state, shall within sixty (60) days from and after the time within which the assessment work required by law to be done upon such claim should have been done and performed, cause to be filed with the clerk of the county in which such mining claim is situated, an affidavit setting forth the time when such work was done, and the amount, character and actual cost thereof, together with the name or names of the person or persons who performed such work; and such affidavit, when made and filed as herein provided, shall be prima facie evidence of the facts therein stated. The failure to make and file such affidavit as herein provided shall, in any contest, suit or proceedings touching the title to such claim, throw the burden of proof upon the owner or owners of such claim to show that such work has been done according to law. [Laws 1897, ch. 58, Sec. 8; C. L. 1897, Sec. 2315; Code 1915, Sec. 3457; C. S. 1929, Sec. 88-113.]

SOUTH DAKOTA

Uranium claims are staked in the same manner as lode claims. The South Dakota Code of 1939 requires as follows:

Section 42.0102. *Dimensions of lode claim.* The length of any lode claim hereafter located within this state may equal but shall not exceed fifteen hundred feet along the vein or lode.

The width of a lode claim shall be three hundred feet on each side of the center of the vein or lode, provided that any county may, at any general election, determine upon a width less than three hundred feet but not less than twenty-five feet on each side of the vein or lode.

Section 42.0103. *Certificate of location and record thereof.* The discoverer of a lode shall within sixty days from the date of discovery record his claim in the office of the register of deeds of the county in which such lode is situated by a location certificate which shall contain:

- (1) The name of the lode;
- (2) The name of the locator or locators;
- (3) The date of location;
- (4) The number of feet in length claimed on each side of the discovery shaft;
- (5) The number of feet in width claimed on each side of the vein or lode;
- (6) The general course of the lode as near as may be;
- (7) Such description of the claim as shall identify it with reasonable certainty.

Section 42.0104. *Location certificate void, when.* Any location certificate of a lode claim which shall not contain the matters specified in Section 42.0103 shall be void.

Section 42.0106. *Certificate limited to single location.* No location certificate shall claim more than one location whether the location be made by one or several locators. If it purports to claim more than one location, it shall be absolutely void

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except as to the first location therein described, and if they are described together or so that it cannot be told which location is first described, the certificate shall be void as to all.

Section 42.0107. *Manner of locating claim.* Before filing such location certificate the discoverer shall locate his claim:

- (1) By sinking a discovery shaft thereon sufficient to show a well defined mineral vein or lode and not less than ten feet in depth on the lower side;
- (2) By posting at the point of discovery on the surface a plain sign or notice containing the name of the lode, the name of the locator or locators, and the date of discovery, the number of feet claimed in length on either side of the discovery, and the number of feet in width claimed on each side of the lode; and
- (3) By marking the surface boundaries of the claim.

Section 42.0108. *Marking surface boundaries.* Such surface boundaries shall be marked by eight substantial posts, hewed or blazed on the side or sides facing the claim and plainly marked with the name of the lode and the corner, end, or side of the claim that they respectively represent and sunk in the ground; one at each corner and one at the center of each side line and one at each end of the lode. When it is impracticable on account of rock or precipitous ground to sink such posts, they may be placed in a monument of stone.

Section 42.0109. *Dimensions of cut or adit.* Any open cut, at least ten foot face cross-cut, or tunnel at a depth sufficient to disclose the mineral vein or lode or an adit of at least ten feet in along the lode from the point where the lode may be in any manner discovered, shall be equivalent to a discovery shaft.

Section 42.0110. *Time allowed for sinking shaft.* The discoverer shall have sixty days from the time of uncovering or disclosing a lode to sink a discovery shaft thereon.

Section 42.0111. *Location includes what.* The location or location certificate of any lode claim shall be construed to include all surface ground within the surface lines thereof and all lodes and ledges throughout their entire depth, the top or apex of which

lie inside of such lines extended vertically with such parts of the lodes or ledges as continue by dip beyond the side lines of the claim but shall not include any portion of such lodes or ledges beyond the end lines of the claim or the end lines continued, whether by dip or otherwise, or beyond the side lines in any other manner than by the dip of the lode.

Section 42.0112. *Limits of claim.* If the top or apex of the lode in its longitudinal course extends beyond the exterior lines of the claim at any point on the surface or as extended vertically downward, such lode may not be followed in its longitudinal course beyond the point where it is intersected by the exterior.

Section 42.0114. *Amended certificate.* If at any time the locator of any mining claim heretofore or hereafter located or his assigns shall apprehend that his original certificate was defective, erroneous, or that the requirements of the law had not been complied with before filing or shall be desirous of changing his surface boundaries or of taking in any part of an overlapping claim which has been abandoned and he shall be desirous of securing the benefit of this chapter, such locator or his assigns may file an additional certificate subject to the provisions of this chapter. Such relocation does not interfere with the existing rights of others at the time of such relocation and no such relocation or the record thereof shall preclude the claimant from proving any such title as he may have held under any previous location.

Section 42.0116. *Abandoned claim: relocation.* The relocation of an abandoned lode claim shall be by sinking a new discovery shaft and fixing new boundaries in the same manner as if it were the location of a new claim, or the relocater may sink the original shaft, cut, or adit to a sufficient depth to comply with the requirements of an original location, and erect new or adopt the old boundaries, renewing the posts if removed or destroyed. In either case a new location stake shall be erected. In any case whether the whole or part of an abandoned claim is taken, the location certificate must state that the whole or any part of the new location is located as abandoned property.

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UTAH

Uranium claims are staked in the same manner as lode claims. The Utah Code* requires as follows:

Paragraph 1 (40-1-1): *Lode claims—Size and shape—Discovery necessary.* A lode mining claim, whether located by one or more persons, may equal, but shall not exceed, 1,500 feet in length along the vein or lode and may extend 300 feet on each side of the middle of the vein at the surface, except where adverse rights render a lesser width necessary. The end lines of each claim must be parallel. No location of a mining claim shall be made until the discovery of the vein or lode within the limits of the claim located.

Paragraph 2 (40-1-2): *Discovery monument—Notice of location—contents.* The locator at the time of making the discovery of such vein or lode must erect a monument at the place of discovery, and post thereon his notice of location which shall contain:

1. The name of the claim.
2. The name of the locator or locators.
3. The date of the location.
4. If a lode claim, the number of linear feet claimed in length along the course of the vein each way from the point of dis-

covery, with the width claimed on each side of the center of the vein, and the general course of the vein or lode as near as may be, and such a description of the claim, located by reference to some natural object or permanent monument, as will identify the claim.

5. If a placer or millsite claim, the number of acres or superficial feet claimed, and such a description of the claim or millsite, located by reference to some natural object or permanent monument, as will identify the claim or millsite.

Paragraph 3 (40-1-3): *Boundaries to be marked.* Mining claims and millsites must be distinctly marked on the ground so that the boundaries thereof can be readily traced.

Paragraph 4 (40-1-4): *Copy of location notice to be recorded.* Within thirty days after the date of posting the location notice upon the claim the locator or locators, or his or their assigns, must file for record in the office of the county recorder of the county in which such claim is situated a substantial copy of such notice of location. Such notice of location shall not be abstracted unless a subsequent conveyance affecting the same property is filed for record, whereupon it shall be abstracted.

WYOMING

Uranium claims are staked in the same manner as lode claims. The Wyoming Compiled Statutes, 1945, require as follows:

Section 57-906. *Amended or additional location—Notices—Relocation certificates.* Whenever it shall be apprehended by the locator, or his assigns, of any mining claims or property heretofore or hereafter located, that his or their original location certificate was defective, erroneous, or that the requirements of the law had not been complied with before the filing thereof, or shall be desirous of changing the surface boundaries of his or their original claim or location, or of taking in any part of an overlapping claim or location, or of taking in any part of an overlapping claim or location which has been abandoned, such locator or locators, or his or their assigns, may file an additional location certificate in com-

pliance with and subject to the provisions of this Act [57-901-57-928]; provided, however, that such relocation shall not infringe upon the rights of others existing at the time of such relocation, and that no such relocation, or other record thereof, shall preclude the claimant or claimants from proving any such title or titles as he or they may have held under any previous location.

Section 57-907. *Location certificates shall describe but one claim.* No location certificate shall contain more than one claim or location, whether the location be made by one or more locators, and any location certificate that contains upon its face more than one location claim shall be absolutely void, except as to the first location named and described therein, and in case more than one claim or location is described to-

* 1953 Utah Code, Annotated, Title 40, Chapter 1.

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gether so that the first one can not be distinguished from the others, the certificate of location shall be void as an entirety.

Section 57-912. *Length of lode claim.* The length of any lode mining claim located within Wyoming, shall not exceed fifteen hundred (1,500) feet measured horizontally, along such lode or vein. Nor can the regulations of any mining district limit a location to less than this length.

Section 57-913. *Width of lode claim.* The width of any lode claim located within Wyoming shall not exceed three hundred (300) feet on each side of the discovery shaft, the discovery shaft being always equally distant from the side lines of the claims. Nor can any mining district limit the location to a width of less than one hundred and fifty (150) feet on either side of the discovery shaft.

Section 57-914. *Recording mining claims—Requisites of certificate.* A discoverer of any mineral lead, lode, ledge, or vein shall, within sixty (60) days from the date of discovery, cause such claim to be recorded in the office of the county clerk and ex officio register of deeds of the county within which such claim may exist, by a location certificate which shall contain the following facts:

1. The name of the lode claim;
2. The name or names of the locator or locators;
3. The date of location;
4. The length of the claim along the vein measured each way from the center of the discovery shaft, and the general course of the vein as far as it is known;
5. The amount of surface ground claimed on either side of the center of the discovery shaft or discovery workings;
6. A description of the claim by such designation of natural or fixed objects, or if upon ground surveyed by the United States System of land survey, by reference to section or quarter section corners, as shall identify the claims beyond question.

Section 57-915. *Imperfect certificates, void.* Any certificate of the location of a lode claim which shall not fully contain all the requirements named in the preceding section, together with such other description as shall identify the lode or claim with reasonable certainty, shall be void.

Section 57-916. *Pre-requisites to filing*

location certificates. Before the filing of a location certificate in the office of the county clerk and ex officio register of deeds, the discoverer of any lode, vein or fissure shall designate the location thereof as follows:

1. By sinking a shaft upon the discovery lode or fissure to the depth of ten (10) feet from the lowest part of the rim of such shaft at the surface;

2. By posting at the point of discovery, on the surface, a plain sign or notice, containing the name of the lode or claim, the name of the discoverer and locator, and the date of such discovery;

3. By marking the surface boundaries of the claim, which shall be marked by six (6) substantial monuments of stone or posts, hewed or marked on the side or sides, which face is toward the claim, and sunk in the ground, one at each corner, and one at the center of each side line, and when thus marking the boundaries of a claim, if any one or more of such posts or monuments of stone shall fall, by necessity, upon precipitous ground, when the proper placing of it is impracticable or dangerous to life or limb, it shall be lawful to place any such post or monument of stone at the nearest point properly marked to designate its right place; provided that no right to such lode or claim or its possession or enjoyment shall be given to any person or persons, unless such person or persons shall discover in said claim mineral bearing rock in place.

Section 57-917. *What open cut equivalent to discovery shaft.* Any open cut which shall cut the vein ten (10) feet in length, and with face ten (10) feet in height, or any crosscut tunnel, or tunnel on the vein ten (10) feet in length which shall cut the vein ten (10) feet below the surface, measured from the bottom of such tunnel, shall hold such lode the same as if a discovery shaft were sunk thereon.

Section 57-918. *Time given discoverer to sink shaft.* The discoverer of any mineral lode or vein in this state shall have the period of sixty (60) days from the date of discovering such lode or vein in which to sink a discovery shaft thereon.

Section 57-920. *Relocation of abandoned claims.* Any abandoned lode, vein or strata

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claim may be relocated and such relocation shall be perfected by sinking a new discovery shaft and by fixing new boundaries in the same manner as provided for the location of a new claim; or the relocater may sink the original discovery shaft ten (10) feet deeper than it was at the time of its abandonment, and erect new, or adopt

the old boundaries, renewing the posts or monuments of stone if removed or destroyed. In either event, a new location stake shall be fixed. The location certificate of an abandoned claim may state that the whole or any part of the new location is located as an abandoned claim.

Appendix XI—Prices and Markets in the United States

UNITED STATES ATOMIC ENERGY COMMISSION DOMESTIC PRICE SCHEDULES

Circular No. 5 (Revised)

GUARANTEED MINIMUM PRICE FOR URANIUM-BEARING CARNOTITE-TYPE OR ROSCOELITE-TYPE ORES OF COLORADO PLATEAU AREA

§ 60.5 *Guaranteed minimum price for uranium-bearing carnotite-type or roscoelite-type ores of the Colorado Plateau area*—(a) *Guarantee.* To stimulate domestic production of uranium-bearing ores of the Colorado Plateau area, commonly known as carnotite-type or roscoelite-type ores, and in the interest of the common defense and security, the United States Atomic Energy Commission hereby establishes the guaranteed minimum prices specified in § 60.5a effective during the period March 1, 1951, through March 31, 1962, for the delivery of such ores to the Commission at Monticello, Utah, in accordance with the terms of this section and § 60.5a.

NOTE: in §§ 60.1 and 60.2 (Domestic Uranium Program, Circulars No. 1 and 2), the Commission established guaranteed prices for other domestic uranium-bearing ores, mechanical concentrates, and refined uranium products.

(b) *Effect on §§ 60.3 and 60.3a.* Sections 60.3 and 60.3a, which also apply to carnotite and roscoelite ores, are not revoked by the issuance of this section and § 60.5a and sellers may elect to deliver ore under the provisions of §§ 60.3 and 60.3a rather than under this section and 60.5a, at their option, during the unexpired terms of §§ 60.3 and 60.3a (through April 11, 1951). It is believed, however, that in most cases the provisions of this section and § 60.5a will be more favorable to producers.

(c) *Definitions.* As used in this section and in § 60.5a, the term "buyer" refers to

the U. S. Atomic Energy Commission, or its authorized purchasing agent. The term "ore" does not include mill tailings or other mill products. The term "seller" refers to any person offering uranium ores for delivery to the Commission. Weights are avoirdupois dry weights, unless otherwise specifically provided.

(d) *Deliveries of not to exceed 1,000 tons per year.* To aid small producers, any one seller may deliver without a written contract but otherwise in accordance with this circular up to, but not exceeding, 1,000 short tons (2,000 pounds per ton) of ores during any calendar year.

(e) *Deliveries in excess of 1,000 tons per year.* Sellers desiring to deliver in excess of 1,000 short tons (2,000 pounds per ton) of ores during any calendar year will be required to enter into a contract with the Commission providing for, among other things, a rate of delivery and the total quantity of ore to be delivered.

(f) *Delivery.* Seller, at his own expense, shall deliver and unload all ores at the buyer's depot at Monticello, Utah. Deliveries shall be in lots of not less than 10 short tons (2,000 pounds per ton) unless special arrangements have been agreed upon by buyer, but such lots may be delivered in more than one load. Days and hours during which ore may be delivered will be posted at the depot.

(g) *Weighing, sampling and assaying.* Buyer will bear the cost of weighing, sampling, and assaying. The net weight of each load will be determined by the buyer's weighmaster on scales which will be provided by the buyer at or in the vicinity of the purchase depot and such weight will be accepted as final. A weight ticket will be furnished seller or his representative for each load. Each lot of ores

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will be sampled promptly by the buyer according to standard practice and such sampling will be accepted as final. Seller or his representative may be present at the sampling at his own expense. The absence of seller or his representative shall be deemed a waiver of this right. Buyer will make moisture determinations according to standard practices in ore sampling. All final samples will be divided into four pulps and distributed as follows: (1) The seller, or his representative, will receive one pulp; (2) the buyer will retain one pulp; (3) the other two pulps will be reserved for possible umpire analysis. The buyer's pulp will be assayed by the buyer. The seller may, if he desires, and at his own expense, have his pulp assayed by an independent assayer. In case of disagreement on assays as to any constituent of the ores, an umpire shall be selected in rotation from a list of umpires approved by the buyer whose assays shall be final if within the limits of the assays of the two parties; if not, the assay which is nearer to that of the umpire shall prevail. The party whose assay is the farther from that of the umpire shall pay the cost of the umpire's assay for the constituent of the ores which is in dispute. In the event that the umpire's assay is equally distant from the assay of each party, costs will be split equally. In case of seller's failure to make or submit assays, buyer's assays shall govern. After sampling, the ores may be placed in process, commingled, or otherwise disposed of by buyer.

(h) *Payment.* Buyer will make payment promptly but payment will not be made until an entire minimum lot of ten short tons (2,000 pounds per ton) has been delivered and accepted, unless special arrangements have been agreed upon by buyer, in which case there may be an extra charge for assaying and sampling. Moisture determinations, analyses and settlement sheets, together with the check in payment, will be mailed to seller.

(i) *Inquiries.* All inquiries concerning the provisions of this section and § 60.5a, offers to deliver ores, or questions about the Commission's domestic uranium program in the Colorado Plateau area should be addressed to:

United States Atomic Energy Commission, Post Office Box 270, Grand Junction, Colorado; Telephone: Grand Junction 3000.

(j) *Licenses.* Arrangements will be made by the Commission for the issuance of licenses, pursuant to the Atomic Energy Act of 1946, covering deliveries of source material to the Commission under this section and § 60.5a.

(k) *Limitation of commitment.* Commitments by the Commission to accept delivery of ores are limited to the provisions of this section and § 60.5a as amended from time to time, or to written contracts between the Commission and sellers. Other commitments purporting to be made by the Commission's field personnel or other agents of the Commission will not bind the Commission unless they are in accord with the provisions of this section and § 60.5a or other official circulars.

§ 60.5a. *Schedule I: minimum prices, specifications, and conditions—*(a) *Prices.* Payment for delivery of the ores will be computed on the following basis:

(1) *Uranium.* (i) Ores assaying less than 0.10 percent: no payment. Any such ores which are delivered to the purchase depot shall, unless otherwise specifically agreed to by buyer, become the property of the buyer as liquidated damages for buyer's expense of weighing, sampling, and assaying, and after sampling may be placed in process, commingled, or otherwise disposed of by buyer. If seller has any question as to the quality of his ore, it is suggested that before shipment and delivery to the purchase depot a representative sample be submitted to the buyer or to one of the umpires for assay at seller's expense. The buyer at its discretion may assay a limited number of samples without charge.

(ii) Ores assaying 0.10 percent U_3O_8 and more, as follows:

| | <i>Payment per pound U_3O_8</i> |
|---------------------------------|--|
| U_3O_8 assay: | |
| 0.10 percent | \$1.50 |
| 0.11 percent | 1.70 |
| 0.12 percent | 1.90 |
| 0.13 percent | 2.10 |
| 0.14 percent | 2.30 |
| 0.15 percent | 2.50 |
| 0.16 percent | 2.70 |
| 0.17 percent | 2.90 |
| 0.18 percent | 3.10 |
| 0.19 percent | 3.30 |
| 0.20 percent and more | 3.50 |

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(iii) Premiums on uranium: \$0.75 per pound for each pound of U_3O_8 in excess of 4 pounds U_3O_8 per short ton (2,000 pounds per ton) or ore and an additional premium of \$0.25 per pound for each pound in excess of ten pounds U_3O_8 per short ton. Fractional parts of a pound will be paid for on a pro rata basis to the nearest cent.

(2) *Vanadium*. V_2O_5 at \$0.31 per pound up to, but not exceeding, ten pounds of V_2O_5 for each pound of U_3O_8 contained in ores. No factor will be included for V_2O_5 in excess of ten pounds for each pound of U_3O_8 , although buyer may, from time to time, publicly announce that, for limited periods by written agreements with individual producers, V_2O_5 in excess of ten-to-one will be paid for. Any such announcement will be made by posting a notice to this effect at the Monticello depot and through such other channels as are deemed suitable to achieve maximum dissemination among producers. Excess V_2O_5 shall be deemed to be buyer's property.

(3) *Allowances*. (i) A development allowance of \$0.50 per pound U_3O_8 contained in ores assaying 0.10 percent U_3O_8 or more in recognition of the expenditures necessary for maintaining and increasing developed reserves of uranium ores. Fractional parts of a pound will be paid for on a pro rata basis to the nearest cent. Sellers accepting this allowance are deemed to agree to spend such funds for the development or exploration of their properties. Sellers delivering less than 1,000 short tons per calendar year will not be required to submit an accounting record of expenditures for development or exploration pursuant to this agreement but sellers delivering in excess of 1,000 short tons per calendar year will be required, under the terms of their contracts, to submit proof satisfactory to the Commission that funds equivalent to the amount received as development allowance have been spent for development or exploration either during the contract period or within six months thereafter, unless otherwise provided in the contract.

(ii) A haulage allowance of 6¢ per ton mile for transportation of ore paid for under §§ 60.5 and 60.5a from the mine where produced to the purchase depot specified by the Commission, up to a maximum of 100 miles. The haulage distance from the mine to the purchase depot will be deter-

mined by the Commission and its decision will be final. Tonnages for purposes of this allowance shall be calculated on the basis of natural weights rather than dry weights.

(4) *Adjustment of assays*. Assays shall be adjusted to the nearest 0.01 percent for purposes of payment.

(b) *Quality and size*. Ores will not be accepted by buyer under §§ 60.5 and 60.5a which, in buyer's judgment:

(1) Contain less than 0.10 percent U_3O_8 ;

(2) Contain more than three parts of lime ($CaCO_3$) to one part of V_2O_5 , or a total of more than 6 percent lime in the ore;

(3) Contain impurities deleterious to buyer's extraction process or for any other reason are not amenable to it;

(4) Contain lumps in excess of twelve inches in size.

NOTE: The Commission will be interested in discussing arrangements for delivery to it of types of uranium-bearing materials other than those for which guaranteed prices have been established, such as tailings, mill products, and ores of types not acceptable under §§ 60.5 and 60.5a.

(60 Stat. 755-775; 42 U. S. C. 1801-1819. Interpret or apply sec. 5, 60 Stat. 761, 42 U. S. C. 1805)

Effective March 1, 1951 through March 31, 1962.

Dated at Washington, D. C., this 26th day of February 1951.

By order of the Commission.

M. W. BOYER,
General Manager.

(F. R. Doc. 51-3190; Filed, Mar. 12, 1951; 8:45 A.M.)

Amended—F. R. Doc. 53-8782; Filed, Oct. 15, 1953; 8:45 A.M.

Circular No. 6

BONUS FOR INITIAL PRODUCTION OF URANIUM ORES FROM DOMESTIC MINES

§ 60.6 *Bonus for initial production of uranium ores from new domestic mines—*

(a) *What this section does*. This section provides for bonus payments for initial and certain other production of uranium-bearing ores. It is intended to encourage and assist the development of new sources of domestic uranium production in the interest of the common defense and security.

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(b) *Production bonus established.* The U. S. Atomic Energy Commission will pay a bonus under the conditions set forth in this section for delivery to a Commission ore-buying station or a qualified uranium mill (hereafter called station or mill) of uranium ores from an eligible mining property up to the maximum quantities specified in this section.

(c) *Term of this section.* This section will apply to deliveries made under its terms between March 1, 1951, and February 28, 1957, inclusive.

(d) *Payment of the bonus.* Bonus payments will be computed on the following basis:

Ores assaying less than 0.10 percent U_3O_8 : no payment.

Ores assaying 0.10 percent U_3O_8 and more, as follows:

| U_3O_8 assay: | Payment per pound of U_3O_8 |
|----------------------------|-------------------------------------|
| 0.10 percent..... | \$1.50 |
| 0.11 percent..... | 1.70 |
| 0.12 percent..... | 1.90 |
| 0.13 percent..... | 2.10 |
| 0.14 percent..... | 2.30 |
| 0.15 percent..... | 2.50 |
| 0.16 percent..... | 2.70 |
| 0.17 percent..... | 2.90 |
| 0.18 percent..... | 3.10 |
| 0.19 percent..... | 3.30 |
| 0.20 percent and more..... | 3.50 |

Fractional parts of a pound will be paid for on a pro rata basis to the nearest cent. Assays will be adjusted to the nearest 0.01 percent for purposes of payment. Weights are avoirdupois dry weights. Bonus payments made under this section will be in addition to any other payments for delivery of the ore. They will be paid directly by the Commission and not by the station or mill.

(e) *Maximum quantity of uranium ores for which bonus payments will be made.* Subject to the conditions of this section, bonus payments will be made on deliveries of uranium ore from an eligible mining property to a station or mill until bonus payments have been made on 10,000 pounds of contained uranium oxide less the number of pounds, if any, accepted by stations or mills (or any other uranium ore processing

plants) from that mining property between April 9, 1948 and February 28, 1951, inclusive.

(f) *Ores for which bonus payments will be made.* Ores for which bonus payments will be made must have been delivered to and paid for by either a station or mill. However, in special cases, bonus payments may be made for ores which have been accepted by the station or mill but for which payment is still pending. Bonus payments will not be made for ores which a station or mill refuses to accept. The weights and final assays made to ascertain the amount of payment due from the station or mill shall be used to determine the amount of bonus payments under this section.

(g) *Which mining properties are eligible.* In order for a mining property to be eligible for bonus payments under this section,

(1) As required by paragraph (e) of this section, the total quantity of uranium oxide as contained in ore accepted by stations or mills (or any other uranium ore processing plants) from that property between April 9, 1948 and February 28, 1951, inclusive, must have been less than 10,000 pounds; and

(2) The property must be within the United States, its territories, possessions or the Canal Zone; and

(3) The property must be certified by the Commission as eligible using the following criteria as guides:

(i) *Purpose of the bonus.* The purpose of the bonus is to encourage and assist the development of new sources of domestic uranium production.

(ii) *Character of mining property.* The mining property may consist of a placer or lode location, or if not covered by location, a tract which the Commission finds to be comparable or otherwise appropriate. However, an entire holding consisting of contiguous locations or tracts will be regarded as only a single eligible unit of mining property if the locations or tracts are held in common in the manner set forth in the following paragraph.

(iii) *Title or interest of the holder of the property.* The title or interest in the mining property should be one of ownership or lawful possession of mining rights. This type of holding will generally be that of an

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owner or leaser (lessee). It is recognized that there are various arrangements such as split check leases, piece rate contracts and the like whereby persons either as employees or independent contractors conduct mining operations on designated areas of property held by another who also supplies certain of the mining services or equipment or both and who receives in return a percentage of the proceeds of the ore produced. In the case of such arrangements, the person who grants the right to conduct these mining operations will be considered as the holder of the mining property although others perform mining operations on it.

(iv) *Minimum size of mining property.* The mining property, if it is made up of a location or locations, should contain at least 15 acres. The minimum size of lands on Indian reservations will be established by the Commission after consultation with the Bureau of Indian Affairs of the Department of Interior. The minimum size of other mining properties will be established by the Commission in individual cases in the light of the purpose of the bonus.

(v) *Subdivision of consolidation of property.* Since the division of existing mining properties into smaller units might have the effect of increasing bonus payments without advancing the purpose of the bonus program, division of a single unit of mining property on or after March 1, 1951, will not be recognized in determining its eligibility for bonus payments under this section. In addition, consolidation or merger of contiguous mining properties on or after March 1, 1951, will not affect the eligibility of the separate properties for bonus payments.

(vi) *Special cases.* Since the above criteria are merely guides to assist the Commission in its decisions, areas which fail to meet all of the criteria may be certified by the Commission as eligible in special cases where it is determined that the deviations are not substantial or that their disqualification would cause serious inequities. In determining whether or not serious inequities would result, the physical characteristics and location of the deposit may be a factor. Under appropriate circumstances, a segment of a certified property may itself be certified as eligible. On

the other hand, technical compliance with all the above criteria will not necessarily make a property eligible.

Properties leased to private operators by the Commission will not be eligible for bonus payments except under special circumstances and as provided for in the lease.

(h) *Determination by the Commission.* The Commission expressly reserves the right to decide the amount of any bonus payments to be made, whether the property should be certified as an eligible mining property, the person to whom the bonus should be paid and whether for any reason a bonus is not payable. These decisions shall rest in the sole discretion of the Commission and shall be final and conclusive. The Commission further reserves the right to establish procedures to carry out the bonus program. Any bonus payments made hereunder with respect to particular ores shall be the only such bonus payments made for those ores. The Commission will not consider any other application for bonus payments on those ores.

(i) *Application for certification.* Applications for certification of a property as eligible should be made to:

U. S. Atomic Energy Commission,
Grand Junction Operations Office
P. O. Box 270,
Grand Junction, Colorado.

The application should include a description of the mining property indicating its size, location, ownership, interest of the applicant and public recording. There should also be included a statement by the applicant that to the best of his knowledge the total quantity of uranium oxide contained in ore accepted by stations or mills (or any other uranium ore processing plants) from that property between April 9, 1948, and February 28, 1951, inclusive, was less than 10,000 pounds. A form prescribed by the Commission and obtainable at a station or mill should be used for supplying the above information. Certification by the Commission will be a prerequisite to payment of the bonus, but after certification, payments will be made for ores which are delivered before certification and which meet the requirements of this section. Normally certification will not be

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made before uranium deposits have been discovered on the property, but the Commission may issue certifications prior to discovery in special cases. The Commission reserves the right to revoke a certification if it determines that its issuance was based on fraud, misrepresentation or mistake or if the requirements of this section are not complied with. The Commission may require such information and right to make such inspections of the mining property as it finds necessary for the purpose of determining its eligibility for bonus payments and the amounts to be paid.

NOTE: Misrepresentation or falsification of facts in an application for certification or for bonus payments may subject the offender to criminal penalties under pertinent provisions of the United States Code including section 1001 of Title 18. Any such offenses also will disqualify the offender from receiving bonus payments.

(j) *Application for bonus payment.* Application for a bonus payment should be made on a prescribed form (obtainable at a station or mill) at intervals not more frequent than once a month during a period when ore deliveries from the property are believed to meet the requirements of this section. Applications may be addressed as follows:

U. S. Atomic Energy Commission,
Grand Junction Operations Office
P. O. Box 270,
Grand Junction, Colorado.

In addition to the application, the Commission may require such other information as it finds necessary.

(k) *Who may apply for bonus payments.* The person (other than a royalty payee or the like) who has lawfully received payment from a station or mill for the delivery of ore from a certified mining property may apply for bonus payments under this section. However, in special cases, the applications of persons whose ores have been accepted by the station or mill but for which payment is still pending will be considered.

(l) *Mill processing ores from its own mines.* In the event that an operator of a mill processes in the mill ores which it obtains from mining properties operated by it, the Commission will pay the bonus

under the conditions set forth in this section to the same extent as if the mining properties were operated by another person who delivered ore to the mill and received payment for it from the mill. In such case, however, the weights and assays used to fix the amount of payment due as a bonus under this section shall be determined in accordance with practices satisfactory to the Commission.

(m) *Definitions.* As used in this section,

(1) "Commission" means the Atomic Energy Commission created by the Atomic Energy Act of 1946, or its duly authorized representative.

(2) "Person" means any individual, corporation, partnership, firm, association, trust, estate, public or private institution, group, or combination thereof. The term "person" shall not include the U. S. or any agency thereof or any officer or employee of the Commission.

(n) *Commission ore-buying stations and qualified uranium mills.* (1) *Stations.* The following are Commission ore-buying stations (that is, ore-buying stations operated on behalf of the Commission):

American Smelting & Refining Co.
Monticello, Utah

American Smelting & Refining Co.
Marysville, Utah

American Smelting & Refining Co.
Edgemont, South Dakota

American Smelting & Refining Co.
Sliprock, New Mexico

American Smelting & Refining Co.
Moab, Utah

(2) *Mills.* The following are qualified uranium mills:

United States Vanadium Company
Uravan, Colo.

United States Vanadium Company
Rifle, Colo.

Climax Uranium Company
Grand Junction, Colo.

Vanadium Corporation of America
Durango, Colo.

Vanadium Corporation of America
Naturita, Colo.

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Vitro Chemical Company
600 West 33d St. South
Salt Lake City, Utah

Anaconda Copper Mining Company
Grants (Bluewater), New Mexico

(3) *Modifications.* These lists may be modified from time to time by public announcement of the Commission.

(o) *Inquiries and communications.* Inquiries about this section and all other communications should be addressed as follows:

U. S. Atomic Energy Commission,
Grand Junction Operations Office
P. O. Box 270,
Grand Junction, Colo.

(p) *Records, rules and regulations.* The Commission may require applicants for

bonus payments under this section to keep for Commission inspection such records concerning production and deliveries of uranium ores for which application is made as it finds proper and may issue such additional rules and regulations relating to bonus payments as it finds necessary or desirable.

(60 Stat. 755-775; 42 U. S. C. 1801-1819)

Dated at Washington, D. C., this 27th day of June 1951.

By order of the Commission.

M. W. BOYER,
General Manager.

(F. R. Doc. 51-7522; Filed, June 29, 1951;
8:53 A.M.)

Amended F. R. Doc. 53-8783;
Filed Oct. 15, 1953; 8:45 A.M.

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SCHEDULE OF PRICES FOR CARNOTITE OR ROSCOELITE TYPE URANIUM ORES OF COLORADO PLATEAU AREA

| Per Cent U ₃ O ₈ | Pounds U ₃ O ₈ | Base Price | | Premium | | Develop. Allowance .50/lb. | Price Before Initial Prod. Bonus and Haulage Allowance | Initial Prod. Bonus (10,000#) | Price Before Haulage Allowance |
|---|---|--|---------------|--------------------|---------------------|----------------------------------|--|--|---|
| | | Pound U ₃ O ₈ | Ton of Ore | .75/lb. 4-lb. + | .25/lb. 10-lb. + | | | | |
| 0.10 | 2.00 | \$1.50 | \$ 3.00 | \$ — | \$ — | \$ 1.00 | \$ 4.00 | \$ 3.00 | \$ 7.00 |
| 0.11 | 2.20 | 1.70 | 3.74 | — | — | 1.10 | 4.84 | 3.74 | 8.58 |
| 0.12 | 2.40 | 1.90 | 4.56 | — | — | 1.20 | 5.76 | 4.56 | 10.32 |
| 0.13 | 2.60 | 2.10 | 5.46 | — | — | 1.30 | 6.76 | 5.46 | 12.22 |
| 0.14 | 2.80 | 2.30 | 6.44 | — | — | 1.40 | 7.84 | 6.44 | 14.28 |
| 0.15 | 3.00 | 2.50 | 7.50 | — | — | 1.50 | 9.00 | 7.50 | 16.50 |
| 0.16 | 3.20 | 2.70 | 8.64 | — | — | 1.60 | 10.24 | 8.64 | 18.88 |
| 0.17 | 3.40 | 2.90 | 9.86 | — | — | 1.70 | 11.56 | 9.86 | 21.42 |
| 0.18 | 3.60 | 3.10 | 11.16 | — | — | 1.80 | 12.96 | 11.16 | 24.12 |
| 0.19 | 3.80 | 3.30 | 12.54 | — | — | 1.90 | 14.44 | 12.54 | 26.98 |
| 0.20 | 4.00 | 3.50 | 14.00 | — | — | 2.00 | 16.00 | 14.00 | 30.00 |
| 0.21 | 4.20 | do | 14.70 | 0.15 | — | 2.10 | 16.95 | 14.70 | 31.65 |
| 0.22 | 4.40 | do | 15.40 | 0.30 | — | 2.20 | 17.90 | 15.40 | 33.30 |
| 0.23 | 4.60 | do | 16.10 | 0.45 | — | 2.30 | 18.85 | 16.10 | 34.95 |
| 0.24 | 4.80 | do | 16.80 | 0.60 | — | 2.40 | 19.80 | 16.80 | 36.60 |
| 0.25 | 5.00 | 3.50 | 17.50 | 0.75 | — | 2.50 | 20.75 | 17.50 | 38.25 |
| 0.26 | 5.20 | do | 18.20 | 0.90 | — | 2.60 | 21.70 | 18.20 | 39.90 |
| 0.27 | 5.40 | do | 18.90 | 1.05 | — | 2.70 | 22.65 | 18.90 | 41.55 |
| 0.28 | 5.60 | do | 19.60 | 1.20 | — | 2.80 | 23.60 | 19.60 | 43.20 |
| 0.29 | 5.80 | do | 20.30 | 1.35 | — | 2.90 | 24.55 | 20.30 | 44.85 |
| 0.30 | 6.00 | 3.50 | 21.00 | 1.50 | — | 3.00 | 25.50 | 21.00 | 46.50 |
| 0.31 | 6.20 | do | 21.70 | 1.65 | — | 3.10 | 26.45 | 21.70 | 48.15 |
| 0.32 | 6.40 | do | 22.40 | 1.80 | — | 3.20 | 27.40 | 22.40 | 49.80 |
| 0.33 | 6.60 | do | 23.10 | 1.95 | — | 3.30 | 28.35 | 23.10 | 51.45 |
| 0.34 | 6.80 | do | 23.80 | 2.10 | — | 3.40 | 29.30 | 23.80 | 53.10 |
| 0.35 | 7.00 | 3.50 | 24.50 | 2.25 | — | 3.50 | 30.25 | 24.50 | 54.75 |
| 0.36 | 7.20 | do | 25.20 | 2.40 | — | 3.60 | 31.20 | 25.20 | 56.40 |
| 0.37 | 7.40 | do | 25.90 | 2.55 | — | 3.70 | 32.15 | 25.90 | 58.05 |
| 0.38 | 7.60 | do | 26.60 | 2.70 | — | 3.80 | 33.10 | 26.60 | 59.70 |
| 0.39 | 7.80 | do | 27.30 | 2.85 | — | 3.90 | 34.05 | 27.30 | 61.35 |
| 0.40 | 8.00 | 3.50 | 28.00 | 3.00 | — | 4.00 | 35.00 | 28.00 | 63.00 |
| 0.41 | 8.20 | do | 28.70 | 3.15 | — | 4.10 | 35.95 | 28.70 | 64.65 |
| 0.42 | 8.40 | do | 29.40 | 3.30 | — | 4.20 | 36.90 | 29.40 | 66.30 |
| 0.43 | 8.60 | do | 30.10 | 3.45 | — | 4.30 | 37.85 | 30.10 | 67.95 |
| 0.44 | 8.80 | do | 30.80 | 3.60 | — | 4.40 | 38.80 | 30.80 | 69.60 |
| 0.45 | 9.00 | 3.50 | 31.50 | 3.75 | — | 4.50 | 39.75 | 31.50 | 71.25 |
| 0.46 | 9.20 | do | 32.20 | 3.90 | — | 4.60 | 40.70 | 32.20 | 72.90 |
| 0.47 | 9.40 | do | 32.90 | 4.05 | — | 4.70 | 41.65 | 32.90 | 74.55 |
| 0.48 | 9.60 | do | 33.60 | 4.20 | — | 4.80 | 42.60 | 33.60 | 76.20 |
| 0.49 | 9.80 | do | 34.30 | 4.35 | — | 4.90 | 43.55 | 34.30 | 77.85 |
| 0.50 | 10.00 | 3.50 | 35.00 | 4.50 | — | 5.00 | 44.50 | 35.00 | 79.50 |
| 0.60 | 12.00 | do | 42.00 | 6.00 | 0.50 | 6.00 | 54.50 | 42.00 | 96.50 |
| 0.70 | 14.00 | do | 49.00 | 7.50 | 1.00 | 7.00 | 64.50 | 49.00 | 113.50 |
| 0.80 | 16.00 | do | 56.00 | 9.00 | 1.50 | 8.00 | 74.50 | 56.00 | 130.50 |
| 0.90 | 18.00 | do | 63.00 | 10.50 | 2.00 | 9.00 | 84.50 | 63.00 | 147.50 |
| 1.00 | 20.00 | 3.50 | 70.00 | 12.00 | 2.50 | 10.00 | 94.50 | 70.00 | 164.50 |
| 2.00 | 40.00 | do | 140.00 | 27.00 | 7.50 | 20.00 | 194.50 | 140.00 | 334.50 |
| 3.00 | 60.00 | do | 210.00 | 42.00 | 12.50 | 30.00 | 294.50 | 210.00 | 504.50 |
| 4.00 | 80.00 | do | 280.00 | 57.00 | 17.50 | 40.00 | 394.50 | 280.00 | 674.50 |
| 5.00 | 100.00 | do | 350.00 | 72.00 | 22.50 | 50.00 | 494.50 | 350.00 | 844.50 |
| 6.00 | 120.00 | 3.50 | 420.00 | 87.00 | 27.50 | 60.00 | 594.50 | 420.00 | 1,014.50 |
| 7.00 | 140.00 | do | 490.00 | 102.00 | 32.50 | 7.000 | 694.50 | 490.00 | 1,184.50 |
| 8.00 | 160.00 | do | 560.00 | 117.00 | 37.50 | 80.00 | 794.50 | 560.00 | 1,354.50 |
| 9.00 | 183.00 | do | 630.00 | 132.00 | 42.50 | 90.00 | 894.50 | 630.00 | 1,524.50 |
| 10.00 | 200.00 | do | 700.00 | 147.00 | 47.50 | 100.00 | 994.50 | 700.00 | 1,694.50 |

PRICES AND MARKETS IN THE UNITED STATES

MARKETS FOR MONAZITE AND OTHER RARE EARTH ORES

Rare Earths, Incorporated
Box 488
R. D. #4
Pompton Plains, New Jersey

Maywood Chemical Works
100 West Hunter Avenue
Maywood, New Jersey

Lindsay Light and Chemical Corporation
258 Ann Street
West Chicago, Illinois

National Carbon Division
Union Carbide & Carbon Corporation
30 East 42nd Street
New York, New York

Mallinckrodt Chemical Works
P. O. Box 8, Bremen Station
St. Louis 7, Missouri

Emergency Procurement Service
General Services Administration
Washington 25, D. C.

MARKETS FOR MINERALS AND ORES OTHER THAN URANIUM AND THORIUM*

BARITE GRINDERS

Possible Buyers of Crude Barite

Acme Barite Co.
Mineral Point, Mo.

Arizona Barite Co.
Box 926
Mesa, Ariz.

Barium Products, Ltd.
Box 8-A
Newark, Calif.

Baroid Sales Division
National Lead Co.
P. O. Box 1675
Houston 1, Texas

The Gliden Co.
Chemical & Pigment Division
766 50th Ave.
Oakland 1, Calif.

Industrial Minerals & Chemical Co.
Sixth and Gilman Sts.
Berkeley, Calif.

Industrial Minerals, Inc.
York, S. C.

Kennedy Minerals Co.
2552 East Olympic Blvd.
Los Angeles 23, Calif.

Magnet Cove Barium Corp.
P. O. Box 6504
Houston 5, Tex.

Mobar Corp.
Mineral Point, Mo.

Mudrite Chemical Corp.
P. O. Box 590
Hatch, N. M.

F. E. Schundler & Co., Inc.
504 Railroad St.
Joliet, Ill.

J. R. Simplot Co.
Boise, Idaho

L. A. Wood
Box 72
Sweetwater, Tenn.

BERYLLIUM

Beryl Ores Co.
Box 409 Route 1
Arvada, Colo.

Beryllium Corp.
Reading, Pa.

* From list compiled by the Minerals Division, U. S. Bureau of Mines, and printed in *Mining World*, Mine Development & Directory Number, April 15, 1953. The Emergency Procurement Service, General Services Administration, Washington 25, D. C., is also a purchaser from time to time of some of the materials listed.

APPENDIX XI

Brush Beryllium Co.
4301 Perkins Ave.
Cleveland 3, Ohio

Clifton Products, Inc.
Painesville, Ohio

Foote Mineral Co.
18 W. Chelton Ave.
Philadelphia 44, Pa.

Philipp Bros., Inc.
70 Pine St.
New York, N. Y.

Varlacoid Chemical Co.
116 Broad St.
New York, N. Y.

COBALT

Ceramic Color & Chemical Mfg. Co.
New Brighton, Pa.

Foote Mineral Co.
18 W. Chelton Ave.
Philadelphia 44, Pa.

Harshaw Chemical Co.
1945 East 97th St.
Cleveland, Ohio

Kennametal, Inc.
Latrobe, Pa.

The Pyrites Co.
Wilmington, Del.

The O. Hommel Co.
Carnegie, Pa.

Shepherd Chemical Co.
Holland Ave.
Cincinnati, Ohio

COPPER

American Metal Co., Ltd.
Carteret, N. J.

American Smelting & Refining Co.
El Paso, Tex.
Garfield, Utah
Hayden, Ariz.
Perth Amboy, N. J.
Tacoma, Wash.

Anaconda Copper Mining Co.
Anaconda, Mont.

Inspiration Consolidated Copper Co.
Inspiration, Ariz.

International Smelting & Refining Co.
Miami, Ariz.
Tooele, Utah
Perth Amboy, N. J.

Kennecott Copper Corp.
McGill, Nev.
Hurley, N. M.

Magma Copper Co.
Superior, Ariz.

Phelps Dodge Refining Corp.
Laurel Hill, N. Y.

Phelps Dodge Corp.
Douglas, Ariz.
Morenci, Ariz.
Ajo, Ariz.

C. Tennant Sons & Co.
Empire State Bldg.
New York 1, N. Y.

Tennessee Copper Co.
Copperhill, Tenn.

GRINDERS OF FELDSPAR

Black Hills Tin Co.
Tinton, S. D.

Carolina Mineral Co., Inc.
Kena, N. C.

Consolidated Feldspar Corp.
Trenton Trust Bldg.
Trenton, N. J.

Eureka Mica Mining & Milling Co.
Portland, Conn.

Feldspar Milling Co.
Burnsville, N. C.

Gladding, McBean & Co.
1919 E. 52nd St.
Los Angeles, Calif.

Northern Feldspars Corp.
W. Rumney, N. H.

Standard Flint & Spar Corp.
1401 New York Ave.
Trenton 7, N. J.

Topsham Feldspar Co.
Brunswick, Maine

PRICES AND MARKETS IN THE UNITED STATES

Western Feldspar Milling Co.
1333 W. Maple Ave.
Denver, Colo.

FLUORSPAR

Brokers or Selling Agents

Balfour, Guthrie, & Co.
Los Angeles, Calif.

Bauer-Wilson & Bateman,
138 S. LaSalle St.
Chicago, Ill.

Continental Ore Co.
500 Fifth Ave.
New York 36, N. Y.

E. I. du Pont de Nemours & Co.
1007 Market St.
Wilmington, Del.

Foote Mineral Co.
18 W. Cheltenham Ave.
Philadelphia 44, Pa.

Hickman, Williams & Co.
Clark Bldg.
Pittsburgh, Pa.

Kerchner, Marshall & Co.
Oliver Bldg.
Pittsburgh, Pa.

E. J. Lavino & Co.
1528 Walnut St.
Philadelphia, Pa.

Mercantile Import & Export Corp.
21 East 40th St.
New York 16, N. Y.

Mercantile Metal & Ore Corp.
60 Wall St.
New York 5, N. Y.

Miller-Adick Co.
Carew Tower
Cincinnati, Ohio

Wm. H. Muller & Co., Inc.
122 East 42nd St.
New York 17, N. Y.

Oglebay Norton & Co.
Hanna Bldg.
Cleveland, Ohio

Frank Samuel & Co.
Lincoln-Liberty Bldg.
Philadelphia, Pa.

Sussex Trading Corp.
1 Newark Ave.
Jersey City, N. J.

Tomlinson & Co.
1500 Walnut St.
Philadelphia, Pa.

Note: Purchases direct from producers are made in a great many instances by the following types of industries: ACID SPAR—aluminum reduction works, certain chemical manufacturers. CERAMIC GRADE—pottery, glass and dishware plants. METALLURGICAL GRADE—ferroalloy producers, steel mills, foundries, cement plants, etc.

LEAD

American Metal Company, Ltd.
61 Broadway
New York 6, N. Y.

American Smelting & Refining Co.
120 Broadway
New York 5, N. Y.

Bunker Hill & Sullivan Mining & Concentrating Co.
Kellogg, Idaho

The Consolidated Mining & Smelting Co., Ltd.
Montreal, Canada

The Eagle-Picher Co.
American Building
Cincinnati 1, Ohio

International Smelting & Refining Co.
25 Broadway
New York 4, N. Y.

Metal Traders, Inc.
67 Wall St.
New York 5, N. Y.

National Lead Company
111 Broadway
New York 6, N. Y.

Philipp Brothers, Inc.
70 Pine St.
New York 5, N. Y.

St. Joseph Lead Co.
250 Park Ave.
New York 17, N. Y.

APPENDIX XI

C. Tennant Sons & Co.
Empire State Bldg.
New York 1, N. Y.

U. S. Smelting, Refining & Mining Co.
75 Federal St.
Boston, Mass.

LEPIDOLITE

Corning Glass Works
Corning, N. Y.

General Electric Co.
Nela Park
Cleveland, Ohio

Foote Mineral Co.
18 W. Cheltenham St.
Philadelphia, Pa.

Pittsburgh Corning Corp.
Port Allegheny, Pa.

MANGANESE ORE

Consumers of Metallurgical-grade Manganese Ore

American Steel Foundries
410 N. Michigan Ave.
Chicago, Ill.

Bethlehem Steel Co.
Bethlehem, Pa.

Colorado Fuel & Iron Corp.
Pueblo, Colo.

Continental Steel Co.
1109 S. Main St.
Kokomo, Ind.

Electro Manganese Corp.
Knoxville, Tenn.

Kaiser Steel Co.
Fontana, Calif.

Lincoln Electric Co.
12818 Coit Road
Cleveland, Ohio

Lone Star Steel Co.
Lone Star, Tex.

Pittsburgh Metallurgical Co.
Niagara Falls, New York

Sheffield Steel Corp.
Kansas City, Mo.

Sloss-Sheffield Steel & Iron Co.
Birmingham, Ala.

Tennessee Products & Chemical Corp.
American National Bank Bldg.
Nashville, Tenn.

U. S. Steel Co.
535 William Penn Place
Pittsburgh 30, Pa.

Woodward Iron Co.
Woodward, Ala.

Consumers of Battery and Chemical- grade Manganese Ores

Acme Battery Co.
59 Pearl St.
Brooklyn, N. Y.

Anchor Hocking Glass Corp.
409 N. Broad St.
Lancaster, Ohio

Arcrods, Inc.
P. O. Box 6686
Sparrows Point, Ind.
Burgess Battery Company
Freeport, Ill.

Foote Mineral Co.
10 E. Cheltenham Ave.
Philadelphia 44, Pa.

General Dry Batteries, Inc.
Cleveland, Ohio

General Electric Co.
Mela Park,
Cleveland, Ohio

E. J. Lavino & Company
1528 Walnut St.
Philadelphia 2, Pa.

Lincoln Electric Co.
12818 Coit Road
Cleveland, Ohio

Ray-O-Vac Company
Madison, Wis.

Tennessee Eastman Corp.
Kingsport, Tenn.

Union Carbide & Carbon Corp.
30 East 42nd St.
New York 17, N. Y.

PRICES AND MARKETS IN THE UNITED STATES

U. S. Electric Mfg. Corp.
222 West 14th St.
New York 11, N. Y.

Verona Chemical Co.
26 Vernon Ave.
Newark, N. J.

Winchester Repeating Arms Co.
New Haven 4, Conn.

MERCURY

Allied Chemical & Dye Corp.
The Solvay Process Div.
P. O. Box 271
Syracuse, N. Y.

American Cyanamid Co.
General Explosives Div.
20 Rockefeller Plaza,
New York 20, N. Y.

American Meter Co.
Eric, Pa.

Automatic Steel Products, Inc.
Mercury Clutch Div.
1201 Camden Ave. S.W.
Canton 6, Ohio

Bailey Meter Co.
1052 Ivanhoe Rd.
Cleveland 10, Ohio

J. T. Baker Chemical Co.
Phillipsburg, N. J.

F. W. Berk & Co., Inc.
Woodridge Div., Box 38
Woodridge, N. J.

Coast Chem. Div.
55 New Montgomery St.
San Francisco, Calif.

L. D. Caulk, Milford, Del.

E. I. du Pont de Nemours & Co., Inc.
Methods Div.
Du Pont Bldg.
Wilmington 93, Del.

Foxboro Co.
Foxboro, Mass.

General Aniline & Film Corp.
General Aniline Works Div.
435 Hudson St.
New York 14, N. Y.

General Color Co.
24 Avenue B
Newark 5, N. J.

General Electric Co.
Purchasing Dept.
1 River Road
Schenectady 5, N. Y.

Gordon I. Gould & Co.
58 Sutter St.
San Francisco 4, Calif.

Mallinckrodt Chemical Works
Jersey City 5, N. J.

Mathieson Chemical Corp.
Mathieson Bldg.
Baltimore 3, Md.

Merck & Co., Inc.
Lincoln Ave.
Rahway, N. J.

The Mercoid Corp.
4201 Belmont Ave.
Chicago 41, Ill.

Metalsalts Corp.
200 Wagaraw Rd.
Hawthorne, N. J.

Minneapolis Honeywell Regulator Co.
2753 4th Ave S.
Minneapolis 8, Minn.

Brown Instrument Div.
4331 Wayne Ave.
Philadelphia, Pa.

Nepera Chemical Co., Inc.
Yonkers 2, N. Y.

Phillips Petroleum Co.
Bartlesville, Okla.

Public Service Electric & Gas Co.
Electric Dept.
80 Park Place,
Newark 1, N. J.

Quicksilver Producers Association,
407 Sansome St.
San Francisco 11, Calif.

Thomas A. Edison, Inc.
Primary Battery Div.
Bloomfield, N. J.

Union Carbide & Carbon Corp.
30 E. 42nd St.
New York 17, N. Y.

APPENDIX XI

U. S. Vanadium Co.
Niacet Chemicals Div.
Box 807
Niagara Falls, N. Y.
Westinghouse Electric Corp.
306 Fourth Ave.
Pittsburgh 30, N. J.
Wyandotte Chemical Corp.
Wyandotte, Mich.

MICA

American Mica Insulation Co.
Frelinghuysen Ave.
Newark, N. J.
Ford Radio & Mica Corp.
536 63rd St.
Brooklyn, N. Y.
General Electric Co.
1 River Road,
Schenectady 5, N. Y.
Huse-Libery Mica Co.
177 Camden St.
Boston, Mass.
Industrial Mica Corp.
945 61st St.
Brooklyn, N. Y.
Reliance Mica Co.
341 39th St.
Brooklyn, N. Y.
Spruce Pine Mica Inc.
Spruce Pine, N. C.
Sylvania Electric Products Inc.
Emporium, Pa.
Western Electric Co., Inc.
Hawthorne Works
195 Broadway
New York 7, N. Y.

MICA GRINDERS

Buyers of Domestic Scrap Mica

Asheville Mica Co.
Biltmore, N. C.—Dry
Concord Mica Corp.
25 Chestnut St.
Penacook, N. H.—Wet
Deneen Mica Co.
Erwin, Tenn.—Dry

Franklin Mineral Products Co.
Franklin, N. C.—Wet and Dry

Richmond Mica Corp.
900 Jefferson Ave.
Newport News, Va.—Wet

Thompson-Weinman
Cartersville, Ga.—Dry

U. S. Mica Co., Inc.
Stamford, Conn.—Dry

Western Nonmetallics, Inc.
Pueblo, Colo.—Dry

MOLYBDENUM CONCENTRATES

J. T. Baker Chemical Co.
Phillipsburg, N. J.

Electro Metallurgical Div.
Niagara Falls, N. Y.

Climax Molybdenum Co.
500 Fifth Ave.
New York 36, N. Y.

Molybdenum Corp. of America
500 Fifth Ave.
New York 36, N. Y.

Republic Steel Corp.
Canton, Ohio

S. W. Shattuck Chemical Co.
Denver, Colo.

NICKEL

American Smelting & Refining Co.
120 Broadway
New York 5, N. Y.

Cosmo Metal Alloys Co.
275 Front St.
New York 7, N. Y.

J. A. Samuel & Co.
220 Broadway
New York, N. Y.

Sulmet Alloys Co., Inc.
Wellington St. and Erie R. R.
Clifton, N. J.

U. S. Smelting, Refining & Mining Co.
1 State St.
Boston, Mass.

PRICES AND MARKETS IN THE UNITED STATES

PYRITE

American Smelting & Refining Co.
120 Broadway
New York 5, N. Y.

Anaconda Copper Mining Co.
25 Broadway
New York 4, N. Y.

Baugh Chemical Company
Baltimore, Md.

Davidson Chemical Corporation
20 Hopkins Place
Baltimore 3, Md.

Foote Mineral Company
18 West Cheltenham Ave.
Philadelphia 44, Pa.

General Chemical Division
Allied Chemical & Dye Corp.
P. O. Box 4040
Denver, Colo.

Norton Company
Worcester, Mass.

Owens Illinois Glass Company
Streator, Ill.

Reliance Phosphate Company
Savannah, Ga.

Stauffer Chemical Company
636 California St.
San Francisco 8, Calif.

SPODUMENE

Corning Glass Works
Corning, N. Y.

Foote Mineral Co.
18 E. Cheltenham Ave.
Philadelphia 44, Pa.

Maywood Chemical Works
Maywood, N. J.

Metalloy Corp.
1320 Rand Tower
Minneapolis, Minn.

National Enameling and Stamping Co.
270 N. 12th St.
Milwaukee, Wis.

Owens Corning Fiberglas Corp.
Newark, Ohio

TITANIUM MINERALS

Ilmenite—Pigment Manufacturers

American Cyanamid Co.
Calco Chemical Div.
Eastern Turnpike
Bound Brook, N. J.

The Chemical & Pigment Co.
6401 St. Helena Ave.
Baltimore 22, Md.

E. I. du Pont de Nemours & Co., Inc.
Methods Div.
Du Pont Bldg.
Wilmington 98, Del.

National Lead Co.
111 Broadway
New York 6, N. Y.

Ilmenite & Rutile—Welding Rod Manufacturers

Actarc, Inc.
P. O. Box 168
Bedford, Ohio

American Brake Shoe Co.
230 Park Ave.
New York 17, N. Y.

Arcos Corp.
1500 So. 50th St.
Philadelphia 43, Pa.

Arcrods Corp.
60 E. 42nd St.
New York 17, N. Y.

Champion Rivet Co.
10931 Harvard Ave.
Cleveland 15, Ohio

Harnischfeger Corp.
4400 W. National St.
Milwaukee, Wis.

Hollup Corp.
4700 W. 19th St.
Chicago 50, Ill.

R. G. LeTourneau, Inc.
Peoria, Ill.

Shober Sales Co.
900 W. Weber Ave.
Stockton, Calif.

A. O. Smith Corp.
3533 N. 27th St.
Milwaukee 1, Wis.

APPENDIX XI

Stoody Co.
Whittier, Calif.

Westinghouse Electric Corp.
306 Fourth Ave.
Pittsburgh, Pa.

Ilmenite & Rutile—Alloy Manufacturers

Aluminum Co. of America
1200 Ring Bldg.
Washington 6, D. C.

Metal & Therman Corp.
120 Broadway
New York 5, N. Y.

Titanium Alloy Mfg., Div.
National Lead Co.
111 Broadway
New York 6, N. Y.

Union Carbide & Carbon Corp.
30 East 42nd St.
New York 17, N. Y.

Vanadium Corp. of America
420 Lexington Ave.
New York 17, N. Y.

Rutile Dealers

Berkshire Chemicals, Inc.
420 Lexington Ave.
New York 17, N. Y.

L. H. Butcher Co.
3628 E. Olympic Blvd.
Los Angeles 23, Calif.

Foote Mineral Co.
18 W. Chelton Ave.
Philadelphia 44, Pa.

International Titanium Corp.
111 Broadway
New York 6, N. Y.

Metal Traders, Inc.
67 Wall St.
New York 5, N. Y.

Orefraction Inc.
7425 Thomas St.
Pittsburgh 8, Pa.

C. Tennant Sons & Co., of New York
Empire State Bldg.
New York 1, N. Y.

TUNGSTEN CONCENTRATES

Bishop Concentrate & Cleaning Co.
Bishop, Calif.

Braeburn Alloy Steel Co.
Div. of Continental Copper & Steel Ind.,
Inc.

Braeburn, Pa.

Columbia Tool Steel Company
Chicago Heights, Ill.

Crucible Steel Company of America
405 Lexington Avenue
New York 17, N. Y.

E. Fernstrom
648 West 3rd Street
Tucson, Ariz.

Ferro Corporation
4150 East 56th Street
Cleveland, Ohio

Firth Sterling & Carbide Corp.
McKeesport, Pa.

Foote Mineral Company
18 West Chelton Ave.
Philadelphia, Pa.

General Electric Company
Cleveland Wire Works
Lamp Dept.
1331 Chardon Road,
Euclid 17, Ohio

Jessop Steel Company
Washington, Pa.

Kennametal, Inc.
Latrobe, Pa.

Latrobe Electric Steel Company
Latrobe, Pa.

Molybdenum Corp. of America
500 Fifth Avenue
New York 36, N. Y.

Shattuck Chemical Company
1805 So. Bannock St.
Denver, Colo.

Sunset Tungsten Mines
Bishop, Calif.

Sylvania Electric Products Co.
Tungsten & Chemical Division
Box 70
Towanda, Pa.

U. S. Vanadium Company
Div. of Union Carbide & Carbon Corp.
30 E. 42 St.
New York 17, N. Y.

PRICES AND MARKETS IN THE UNITED STATES

Vanadium Alloy Steel Company
Latrobe, Pa.

Vulcan Crucible Steel Company
Aliquippa, Pa.

Wah Chang Corporation
Woolworth Building
New York 7, N. Y.

Westinghouse Electric Corp.
1-71 MacArthur Avenue,
Bloomfield, N. J.

ZINC

The American Metal Co., Ltd.
61 Broadway
New York 6, N. Y.

American Smelting & Refining Co.
120 Broadway
New York 5, N. Y.

American Zinc Co. of Illinois
1600 Paul Brown Bldg.
St. Louis, Mo.

Anaconda Copper Mining Co.
25 Broadway
New York 4, N. Y.

Associated Metals & Minerals Corp.
75 West St.
New York 6, N. Y.

Athlet'c Mining & Smelting Co.
Fort Smith, Ark.

E. I. du Pont de Nemours & Co.
1007 Market St.
Wilmington, Del.

Eagle-Picher Co.
American Bldg.
Cincinnati 1, Ohio

Eagle-Picher Mining & Smelting Co.
Miami, Okla.

W. R. Grace & Company
Hanover Square
New York, N. Y.

The Hegler Zinc Company
Danville, Ill.

International Minerals & Metals Corp.
11 Broadway
New York 4, N. Y.

Mathiesen & Hegler Zinc Co.
La Salle, Ill.

Metal Traders, Inc.
67 Wall St.
New York 5, N. Y.

New Jersey Zinc Co.
160 Front St.
New York 7, N. Y.

Philipp Brothers, Inc.
70 Pine Street
New York 5, N. Y.

St. Joseph Lead Co.
250 Park Ave.
New York 17, N. Y.

The Sherwin-Williams Co.
Ozark Smelting & Mining Division
101 Prospect Ave., N.W.
Cleveland 1, Ohio

Sullivan Mining Co.
Box 209
Kellogg, Idaho

C. Tennant Sons & Co.
Empire State Bldg.
New York 1, N. Y.

U. S. Steel Corp.
436 Seventh Ave.
Pittsburgh 30, Pa.

United Zinc Smelting Corp.
50 Union Square
New York 3, N. Y.

ZIRCON

F. W. Berk & Co.
Woodridge, N. J.

Cohart Refractories Co.
Louisville, Ky.

Electro Metallurgical Div.
Union Carbide & Carbon Corp.
30 E. 42nd St.
New York 17, N. Y.

Foote Mineral Co.
18 W. Cheltenham Ave.
Philadelphia 44, Pa.

International Titanium Corp.
120 Broadway
New York 5, N. Y.

APPENDIX XII

Orefraction, Inc.
7505 Meade St.
Pittsburgh, Pa.

Titanium Alloy Mfg. Div.
National Lead Co.
111 Broadway
New York 6, N. Y.

Appendix XII—Information on Canada

POLICY, REGULATIONS AND AID TO PROSPECTORS*

WHO MAY PROSPECT

Any resident of Canada may search for radioactive mineral deposits without obtaining a special permit. Restrictions in effect during the war have been removed, and prospecting and staking claims for uranium and thorium minerals are now on exactly the same basis as for the commoner minerals. The finder of a deposit of uranium or thorium minerals may sell, develop, mine, or otherwise dispose of his claim or claims just as in the case of other minerals.

IMPORTING PROSPECTING EQUIPMENT

Portable Geiger counters and like instruments for detecting radioactive minerals were formerly imported duty free, but they are now subject to duty. They may, however, be purchased without payment of sales tax if the purchaser will use them directly in the process of manufacture or production of goods and so certify on his purchase order or the Customs Import Entry. The Department of National Revenue has regarded prospecting as part of the production of goods.

Prospectors who are permanent residents of other countries and who are entering Canada temporarily may bring in personal effects, including tools of trade, such as hammers, saws, and like tools, when for personal use and actually in possession of the importer at time of arrival in this country, under a Temporary Admission Report Form E.29, permit, without Customs charge, provided the articles are exported under Customs supervision within the prescribed time. Geiger counters and other such precision instruments are subject, however, to the ordinary provisions of the tariff.

Regulations regarding customs duties and sales tax may change from time to time. Inquiries should be addressed to the Deputy

Minister of Customs and Excise, Department of National Revenue, Ottawa, Canada.

STAKING CLAIMS FOR URANIUM

Staking of mineral claims for uranium and thorium minerals or any other minerals is subject to the mining laws of the province or territory in which the prospecting is done.

In order to stake claims for uranium or other minerals, a prospector's licence must be obtained. These are issued by the various provincial governments for the provinces and by the Department of Resources and Development, Ottawa, for the territories. Information in regard to mining laws, prospectors' licences, staking claims, etc., may be obtained on application as below:

British Columbia—Deputy Minister of Mines, Mines Department, Victoria, B. C.
Alberta—Deputy Minister of Lands and Mines, Department of Lands and Mines, Edmonton, Alberta.

Saskatchewan—Deputy Minister, Department of Mineral Resources, Regina, Saskatchewan.

Manitoba—Director of Mines, Department of Mines and Natural Resources, Winnipeg, Manitoba.

Yukon and Northwest Territories—Director, Development Services Branch, Department of Resources and Development, Ottawa.

Ontario—Deputy Minister, Department of Mines, Toronto, Ontario.

Quebec—Deputy Minister, Department of Mines, Quebec, Que.

New Brunswick—Deputy Minister, Department of Lands and Mines, Fredericton, N. B.

Nova Scotia—Deputy Minister, Department of Mines, Halifax, N. S.

* From *Prospecting for Uranium in Canada*, published by Department of Mines and Technical Surveys, Ottawa, 1952.

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Prince Edward Island—Deputy Provincial Secretary, Provincial Government Offices, Charlottetown, Prince Edward Island.

Newfoundland—Director of Crown Lands and Surveys, Department of Natural Resources, St. John's, Newfoundland.

FEDERAL GOVERNMENT SUPERVISION

Only after a deposit of radioactive minerals has been found is some degree of supervision exercised by the federal government. This supervision has been designed to cause as little inconvenience as possible to those wishing to develop deposits of radioactive minerals while at the same time enabling the Government to secure information as to the uranium resources of the country and to control the disposal of any important quantities of uranium or thorium minerals produced. This is effected through: the Atomic Energy Control Act, 1946; the regulations of the Atomic Energy Control Board; and orders issued by the Atomic Energy Control Board.

The Atomic Energy Control Act, 1946, established the Atomic Energy Control Board to deal with the practical aspects of atomic energy. Regulations and orders of the Board have the status of laws, and penalties may be imposed upon anyone convicted of failure to observe the requirements. Extracts from the Atomic Energy Control Act, 1946, and Regulations of the Atomic Energy Control Board, so far as they relate to prospecting, exploration, and mining, are quoted in appendices at the back of this booklet. Orders and press releases of the Atomic Energy Control Board are given in full in other appendices. So far as they affect the prospector, the regulations, orders, and press releases may be summarized as follows.

REPORTING REQUIRED BY THE ATOMIC ENERGY CONTROL BOARD

The Director, Geological Survey of Canada, acts as agent for the Atomic Energy Control Board in collecting and filing information required in regard to: (1) the results of assays or analyses made for uranium and thorium; (2) the localities from which samples analysed were obtained and the location of new finds; (3) the progress of exploratory work and its results on properties operating under Atomic Energy

Control Board orders or exploration permits.

Prospectors and those developing radioactive mineral deposits are responsible for supplying the information indicated by the section in *italics* below.

All assays or analyses of materials showing a content of more than 0.05 per cent uranium or thorium element must be reported by the analyst, together with the name and address of the sender of the sample, to the Director, Geological Survey of Canada, Ottawa, Ontario. If the source of the material analysed is known, this must also be reported, *otherwise the sender of the sample is required to promptly inform the Director, Geological Survey of Canada, of the location of the deposit from which the sample assayed was taken and of the size and nature of the deposit so far as can be ascertained. A prospector who without having assays made, has reason to believe or suspect (as from high Geiger counter or scintillometer readings or identification of pitchblende in the deposit) that his discovery contains material of more than 0.05 per cent uranium or thorium content must also promptly report the location of his discovery to the Director of the Geological Survey of Canada, Ottawa.*

On request, time will be allowed for staking claims before reporting locality information.

The discoverer of a radioactive mineral deposit may make public his find *after* informing the Director, Geological Survey of Canada, of the discovery, but information supplied to the Director, as to analyses or localities, is held as confidential until released by those concerned, either by publication or by request.

Uranium or thorium assays made in the United States of America or other countries on materials from Canadian deposits must be reported to the Director, Geological Survey of Canada, by the senders of the samples.

APPLYING FOR EXPLORATION PERMITS

Anyone wishing to explore a radioactive mineral deposit by diamond drilling, surface work, test pitting, or preliminary underground work, or to ship large bulk samples for test is required to obtain an exploration permit from the Atomic Energy Control Board. Such permits are issued free of charge on application to the Secretary,

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Atomic Energy Control Board, Ottawa, and on supplying him with the following information:

1. The full name and address of the applicant and, if the applicant is a corporation, the manner of its incorporation and the names and addresses of all of its directors and officers;
2. The name and address of the person who will be in charge of the work on the ground;
3. A complete and accurate description by record claim number, mining district and province, or by lot and concession number, township, county or district, and province of all property intended to be covered by the order;
4. A general description of the work contemplated.

Exploration permits specify that quarterly reports shall be sent in duplicate to the Director, Geological Survey of Canada, Ottawa, showing fully and accurately the work done and the results of exploration of the property up to the end of the preceding month. The information required includes a summary report and copies of all diamond drill-hole logs, plans, reports of analyses, radiometric tests, and any other pertinent information.

TAKING SMALL SAMPLES FOR ANALYSIS OR DISPLAY

No permit is necessary to authorize taking small prospector's samples, such as hand samples, channel samples, or other such samples as are usually taken for analysis or display purposes and weighing no more than 5 or 10 pounds each. No amount of radioactive mineral-bearing material greater than is required for analysis or display purposes may be removed from a deposit without permission from the Atomic Energy Control Board.

DISPOSAL OF ORES AND CONCENTRATES

Ores or concentrates containing more than 0.05 per cent uranium or thorium may not be removed from the place of origin or sold to anyone except the Government without permission from the Atomic Energy Control Board.

GOVERNMENT PURCHASE OF ORES OR CONCENTRATES

Eldorado Mining and Refining Limited, as agent for the Government, will purchase

acceptable ores or concentrates at prices fixed by the Government and guaranteed for a term of years. Acceptable ores or concentrates are defined as containing a minimum of 10 per cent of uranium oxide (U_3O_8), but under special circumstances consideration may be given to payment of a higher price or to acceptance of ores or concentrates of lower grade.

The maximum price that will be paid per pound of U_3O_8 contained in acceptable ores or concentrates is \$7.25 for the first 3 years of production. Special inquiries in regard to price arrangements or other matters in connection with marketing ores or concentrates, etc., should be addressed to the President, Eldorado Mining and Refining Limited, Ottawa, Canada.

Thorium Ores Not Purchased. The Government does not purchase thorium ores, nor is any allowance made for a thorium content in purchasing uranium concentrates nor for the radium content of uranium minerals, but arrangements will be made for valuing any other constituents that can be recovered commercially.

Ores of metals or elements other than uranium or thorium carrying less than 0.05 per cent uranium or thorium are not subject to Atomic Energy Control Board orders and may be dealt with without regard to the uranium or thorium content. In doubtful cases, the Secretary, Atomic Energy Control Board, Ottawa, should be consulted.

SPECIMENS FOR SCIENTIFIC PURPOSES

Specimens of uranium-bearing or thorium-bearing minerals for mineralogical or other scientific purposes may be sold, presented, or exchanged within Canada, subject to the regulation that such dealings do not involve during any calendar year a total of more than 10 kilograms (22 pounds) of contained uranium or thorium element, and that any other regulations that may apply are observed. In doubtful cases, the Secretary, Atomic Energy Control Board, Ottawa, should be consulted.

FEDERAL NON-PARTICIPATION IN PRIVATE PROSPECTING AND DEVELOPMENT

No cash reward for the finding of radioactive mineral deposits is offered by the federal government or by any of the provincial governments. Earlier laws of On-

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tario and British Columbia providing a cash payment for the finding of radium ore in commercial quantity have lapsed or been repealed.

The Government does not ordinarily buy uranium-bearing deposits or assist financially in their development. Eldorado Mining and Refining Limited, the Crown company, as agent of the Government, however, has the same privileges as other companies, and may buy or sell uranium-bearing properties if it so desires.

Neither the Geological Survey of Canada nor other federal governmental organization assists prospectors in the search for radioactive mineral deposits by financial aid or by loaning or renting Geiger counters or other equipment.

PROVINCIAL AID TO PROSPECTORS

The provinces of British Columbia and Saskatchewan assist prospectors in various ways. In British Columbia, the "Prospectors' Grub-Stake Act," as amended in March 1944, provides for grub-stakes of up to \$300 to prospectors, plus an additional amount of as much as \$200 if travelling expenses are to be paid. Saskatchewan assists in other ways. Inquiries should be addressed to: the Deputy Minister, Department of Mines, Victoria, B. C., and the Deputy Minister, Department of Mineral Resources, Regina, Saskatchewan.

EXAMINATION OF DISCOVERIES BY GOVERNMENT GEOLOGISTS

Prospectors who have found a radioactive mineral deposit often ask the Geological Survey of Canada to send a geologist immediately to examine the discovery. Unfortunately, owing to the great number of small discoveries constantly being made and the limited number of field officers available, the Geological Survey cannot meet all such demands, although an effort is made to examine all the more promising new finds as promptly as possible. Prospectors may also apply to the Mines Department of the province in which they are working to have their discoveries examined by a provincial geologist.

¹ The number of samples tested by the Geological Survey is now limited to six from any one unstaked occurrence or from any one group of claims.

FREE TESTING OF PROSPECTORS' SAMPLES BY THE GEOLOGICAL SURVEY OF CANADA

Prospectors may send their samples for testing to private analysts or to laboratories of provincial mining departments, or they may have their samples tested quantitatively for radioactivity without charge by the Geological Survey of Canada.¹ Samples for test should be addressed to the Director, Geological Survey of Canada, attention Radioactive Resources Division, and should be plainly marked "for radioactivity test" on the tag or outside of the parcel. Transportation charges on samples must be pre-paid by the sender. The sender's name and address should be marked on the tag or outside of the parcel or should be enclosed in the parcel. Letters pertaining to samples should be mailed when the samples are sent, or earlier, and should be addressed to the Director, Geological Survey of Canada, attention Radioactive Resources Division. Letters and reports addressed to the Director, Geological Survey of Canada, may be sent post free O.H.M.S.

Identifications of radioactive minerals not requiring chemical analysis will be made by the Geological Survey on request, without charge, according to priority ratings based on grade and origin of the sample. Such identifications will ordinarily indicate the group to which the mineral belongs, from which the range of content of the constituent elements may be inferred by reference to analyses of known members of the group concerned.

In sending samples for tests or radioactive mineral identifications it is advisable to designate each sample or lot of samples that is to be tested separately by a number or letter, along with any description or details of the occurrence that may be given. When a number of samples are sent for individual tests in one parcel, the different samples should be very securely wrapped and tied or, preferably, enclosed in cloth sample bags to avoid the possibility of breakage and mixing during shipment.

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CHEMICAL ANALYSES

Samples sent to the Geological Survey for tests should ordinarily be at least a pound or two in weight. If identification of the radioactive mineral or minerals present is desired, a special sample of the richest and least altered material available will facilitate the work of separating some of the radioactive mineral in pure condition for the necessary tests. Other samples should, if possible, represent average grade over known widths.

A special effort is made by the radioactivity laboratory of the Geological Survey of Canada to send out the results of quantitative radioactivity tests to prospectors as quickly as possible. Most samples received are tested and results mailed the same day as received. On request, test results will be sent by telegram or phoned, charges to be paid by the senders of the samples.

Identifications of the radioactive minerals present in prospectors' samples ordinarily require more time than radioactivity tests. In many instances elaborate separation and concentration procedures are necessary in order to obtain some of the mineral responsible for the radioactivity in sufficiently pure form for identification tests. Hence, for this reason and because of the effect of priority ratings, it may not be possible to forward the results of identification tests until a considerable time after the sample is received.

Results of Tests Held as Confidential. Results of tests by the radioactivity laboratory of the Geological Survey of Canada are held as confidential by the Geological Survey until released by those concerned, by publication or otherwise.

The Geological Survey of Canada does not make chemical analyses for uranium and thorium for the public. A list of private analysts who make these determinations will be found in the footnote below.¹

The laboratories of the provincial mines departments of British Columbia, Manitoba, Ontario, and Quebec also make chemical analyses for uranium, as well as radiometric tests on prospectors' samples.

The Mines Branch, Department of Mines and Technical Surveys, Ottawa, does not make free radiometric and chemical assays for uranium, except those related to concentration and extraction tests. This is because several firms now offer adequate radiometric and analytical services. It has always been the policy of the Mines Branch to make assays and analyses for gold and other metals when these are desired for some special reason, and to charge slightly more than commercial rates in order to avoid competition with commercial firms. This policy now applies to assays for uranium, which will be made only for special reasons and at a charge of \$10 each.

Chemical assays for thorium are usually costly and difficult, and will not normally be undertaken by the Mines Branch. However, in some cases estimations can be made from radiometric measurements, and such estimates will be made free of charge, upon request, when the Mines Branch has been satisfied that the material is of sufficient interest.

¹The following is a list of assayers known to have performed chemical analyses for uranium; some also make thorium determinations:

G. S. Eldridge and Co., Ltd., 537 Hornby St., Vancouver, B. C.
J. R. Williams and Son, 580 Nelson St., Vancouver, B. C.
E. W. Widdowson and Co., 301-305 Josephine St., P. O. Box 610 Nelson, B. C.
Milton Hersey Co. Ltd., 233 Fort St., Winnipeg
Sudbury Assay Office, 256 Oak St., Sudbury, Ontario.
Temiskaming Testing Laboratories, Cobalt, Ontario.
Thomas Heys and Sons, Room 77-79 Toronto Arcade, Yonge St., Toronto.
Toronto Testing Laboratory Ltd., 73 Adelaide St., W., Toronto.
Lakefield Research, Ltd., Lakefield, Ontario.
Mr. H. Weller, Cobden, Ontario.
Milton Hersey Co. Ltd., 980 St. Antoine St., Montreal.

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FREE CONCENTRATION AND EXTRACTION TESTS BY THE MINES BRANCH

Those wishing to test the possibilities of a promising discovery by further development and bulk sampling should communicate with the Mines Branch, Department of Mines and Technical Surveys, in regard to having concentration and extraction tests made on representative material from the deposit.

The Radioactivity Division of the Mines Branch is equipped to carry out, free of charge, concentration and extraction tests on uranium ores that warrant such work being performed. These tests will determine the average uranium content of the sample, its suitability for treatment, and the percentage of recovery.

Preliminary test work may be done on samples containing between 0.05 and 0.1 per cent U_3O_8 in order to determine their adaptability to concentration; however, as a general rule, ore should assay more than 0.1 per cent U_3O_8 to warrant full-scale concentration test work being performed. In general, factors that determine whether a uranium-bearing rock can be classed as ore are location, grade, size, and general characteristics of the deposit. These factors should be borne in mind when submitting samples for concentration work.

Samples submitted for such work should be as representative as possible of the deposit that is to be mined, and they should be blasted from fresh materials so as to contain a minimum of alteration products. *Each sample should be at least 300 pounds in weight. Exploration permits authorize taking bulk samples to a total not exceeding 10 tons in weight for mill tests.* Samples should be shipped prepaid.

Before shipping bulk samples for concentration tests, permission to remove the samples should be obtained from the Secretary, Atomic Energy Control Board, Ottawa, and specific information regarding the location, approximate grade, and size of the deposit

should be submitted to the Mines Branch. Shipments should not be made until the Mines Branch has agreed to undertake the test work. Letters and samples should be addressed to: The Chief, Radioactivity Division, Mines Branch, 30 Lydia Street, Ottawa, Canada.

OTHER SERVICES OF THE GEOLOGICAL SURVEY OF CANADA

Literature on Canadian uranium deposits, data on portable Geiger counters and scintillation type equipment, copies of regulations of the Atomic Energy Control Board relating to prospecting, and related information may be obtained on application to the Director, Geological Survey of Canada, attention Radioactive Resources Division. Geological maps and reports are supplied by the Geological Survey of Canada, and geological maps, reports, and information on mining laws may also be obtained from provincial mines departments.

Small specimens of pitchblende ore for testing Geiger counters, etc., may be obtained by applying to the Director, Geological Survey of Canada, attention Radioactive Resources Division. These are sent postpaid on receipt of the amount of the charge (50 cents) in the form of a postal note or money order made out to the Receiver General of Canada. Stamps and cheques are not acceptable.

Prospectors wishing to search for minerals other than those of uranium and to study the general principles involved in searching for mineral deposits will find the set of four textbooklets on "Mining" prepared by the Canadian Legion Educational Services very interesting and useful. The set may be obtained from the Publications Officer, Geological Survey of Canada, at a cost of \$1. The individual volumes comprising the set are not sold separately. Payment should be by postal note or money order made out to the Receiver General of Canada. Stamps and cheques are not acceptable.

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GOVERNMENT PURCHASING POLICY FOR URANIUM ORES AND CONCENTRATES*

As several announcements have been made in regard to the purchase of uranium ores and concentrates, the later ones are more easily understood by considering all of them in order, commencing with the first announcement by the Right Honourable C. D. Howe, on March 16, 1948, as follows:

"The government will purchase through Eldorado Mining and Refining Limited, or other designated agency, acceptable uranium bearing ores and concentrates on the following basis:

1. A minimum uranium content equivalent to 10 per cent by weight of uranium oxide (U_3O_8) in the ores or concentrates will normally be required.
2. Price will be based upon the uranium content of the ores or concentrates and will be at the minimum rate of \$2.75 per pound of contained (U_3O_8) f.o.b. rail and will be guaranteed for a period of five years.
3. This price includes all radioactive elements in the ores or concentrates, but consideration will be given to the commercially recoverable value of non-radioactive constituents by adjustment of price or by the redelivery of the residues containing such constituents.
4. Under special circumstances, consideration may be given to payment of a higher price or to acceptance of ores or concentrates of lower grade.
5. All operations will be carried on subject to the provisions of the Atomic Energy Regulations of Canada."

On December 20, 1948, the expiry date for the guaranteed floor price was extended to March 31, 1955.

A further amendment to the purchasing policy was announced by Mr. W. J. Bennett,¹ President and Managing Director, Eldorado Mining and Refining Limited, at the Annual Meeting of the Canadian Institute of Mining and Metallurgy, Toronto, April 18, 1950. This was designed to encourage the development of low-grade

deposits and efficiency in ore dressing by payment of a milling allowance on ore treated. The formula for determining the price to be paid for the U_3O_8 content of concentrates is based upon four factors:

- (1) \$2.75 a pound for the average U_3O_8 content of the ore or mill feed
- (2) A milling allowance of \$7.25 a ton of ore milled
- (3) A maximum price based on a mill head of 0.25 per cent U_3O_8
- (4) A minimum extraction of 70 per cent

Eldorado Mining and Refining Limited will purchase, f.o.b. rail, acceptable concentrates, which normally will be required to contain a minimum uranium content equivalent to 10 per cent by weight of uranium oxide (U_3O_8) and will pay for the U_3O_8 content at a price per pound determined in accordance with the following formula:

The price per pound to be paid for the U_3O_8 content of acceptable concentrates containing 10 per cent or more by weight of U_3O_8 shall be the product obtained by multiplying the average number of pounds of U_3O_8 per ton of mill feed by \$2.75 a pound, adding to this a milling allowance of \$7.25 per ton of ore milled, and dividing the sum of the two by 70 per cent of the average number of pounds of U_3O_8 per ton of mill feed.

The maximum price per pound for the U_3O_8 content of acceptable concentrates that will be paid under this arrangement is that based upon the formula applied to an ore with an average grade of 0.25 per cent or 5 pounds per ton.

As the price is based upon the average grade, Eldorado reserves the right to adjust the contract from time to time to bring it into conformity with actual operating results.

The formula is designed to encourage efficiency in ore dressing. Although the minimum extraction of 70 per cent is used in the formula, it will be apparent that

* From *Prospecting for Uranium in Canada*, published by Department of Mines and Technical Surveys, Ottawa, 1952.

¹ Remarks of W. J. Bennett on Purchasing Policy at Annual Meeting of C.I.M.M., Toronto, April 18, 1950; obtainable on application to the Secretary, Atomic Energy Control Board, Ottawa, Ontario.

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if recovery exceeds 70 per cent there will be more pounds of U_3O_8 to be purchased. Hence the value per ton of ore mined and milled will be greater.

Although the price includes all radioactive elements in the concentrates, arrangements will be made for valuing other constituents that can be recovered commercially.

The following examples show how the formula is applied:

| | | |
|--|-------------------|-----------------|
| (1) Grade of ore, 0.25 per cent, or 5 pounds a ton | $5 \times \$2.75$ | \$13.75 |
| Milling allowance | 7.25 | |
| Value of ore per ton | | \$21.00 |
| Recovery, 70 per cent of 5 pounds = 3.5 pounds | | |
| Price to be paid for the U_3O_8 content of concentrates: | | |
| $\$21.00 \div 3.5$ | | \$ 6.00 a pound |

| | | |
|--|--------------------|-----------------|
| (2) Grade of ore, 0.5 per cent, or 10 pounds a ton | $10 \times \$2.75$ | \$27.50 |
| Milling allowance | 7.25 | |
| Value of ore per ton | | \$34.75 |
| Recovery 70 per cent of 10 pounds = 7 pounds | | |
| Price to be paid for the U_3O_8 content of concentrates: | $\$34.75 \div 7$ | \$ 4.95 a pound |

| | | |
|--|---------------------|-----------------|
| (3) Grade of ore, 0.75 per cent, or 15 pounds a ton | $15 \times \$2.75$ | \$41.25 |
| Milling allowance | 7.25 | |
| Value of ore per ton | | \$48.50 |
| Recovery 70 per cent of 15 pounds = 10.5 pounds | | |
| Price to be paid for the U_3O_8 content of concentrates: | $\$48.50 \div 10.5$ | \$ 4.62 a pound |

The Right Honourable C. D. Howe, on April 17, 1950, announced the extension of the guaranteed price period to March 31, 1958.

On March 6, 1951, Mr. Bennett¹ announced a further revision in the price schedule by which the price paid per pound of U_3O_8 content for mill products produced during the first 3 years of production, or any part thereof, will be increased by \$1.25 a pound. Thus, for example, the U_3O_8 content of a concentrate produced from an ore with an average grade of 0.25 per cent or lower will be paid for at the rate of \$7.25 a pound during the first 3 years of production. In the case of a concentrate produced from ore of 0.5 per cent average grade, the new price will be \$6.20 a pound of U_3O_8 content, for the first 3 years, and so on.

The period during which these prices are guaranteed was also extended to April 1, 1960.²

¹ Address of W. J. Bennett, President, Eldorado Mining and Refining Limited, at the Annual Convention, Prospectors and Developers Association, and Fourth Annual Meeting, Geological Association of Canada, Toronto, March 6, 1951; obtainable on application to the Secretary, Atomic Energy Control Board, Ottawa, Ontario.

² Now further extended to April 1, 1962.

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EXTRACTS RELATING TO PROSPECTING AND MINING, FROM THE ATOMIC ENERGY CONTROL ACT, 1946*

1. This Act may be cited as The Atomic Energy Control Act, 1946.
2. In this Act, unless the context otherwise requires,
 - (a) "atomic energy" means all energy of whatever type derived from or created by the transmutation of atoms;
 - (b) "Board" means the Atomic Energy Control Board established by section three of this Act;
 - (c) "Chairman" means the Chairman of the Committee of the Privy Council on Scientific and Industrial Research as defined in the Research Council Act;
 - (d) "Committee" means the Committee of the Privy Council on Scientific and Industrial Research as defined in the Research Council Act;
 - (e) "company" means a company incorporated pursuant to paragraph (a) of subsection one of section ten and any company the direction and control of which is assumed by the Board pursuant to paragraph (b) of subsection one of section ten of this Act;
 - (f) "member" means a member of the Board;
 - (g) "President" means the President of the Board; and
 - (h) "prescribed substances" means uranium, thorium, plutonium, neptunium, deuterium, their respective derivatives and compounds and any other substances which the Board may by regulation made under this Act designate as being capable of releasing atomic energy, or as being requisite for the production, use or application of atomic energy.
3. (1) There is hereby constituted a body corporate to be called the Atomic Energy Control Board for the purposes hereinafter set out and with powers exercisable by it only as an agent of His Majesty.
 - (2) The Board may on behalf of His Majesty contract in the name of His Majesty and property acquired by the Board is the property of His Majesty except shares in the capital stock of a company which shall be vested in the name of the Board in trust for His Majesty.
4. (1) The Board shall consist of the person who from time to time holds the office of President of the Honorary Advisory Council for Scientific and Industrial Research as defined in the Research Council Act and four other members appointed by the Governor in Council.
7. The Board shall comply with any general or special direction given by the Committee with reference to the carrying out of its purposes and shall advise the Committee on all matters relating to atomic energy, which, in the opinion of the Board, may affect the public interest.
8. The Board may,—
 - (a) undertake or cause to be undertaken researches and investigations with respect to atomic energy;
 - (b) with the approval of the Governor in Council utilize, cause to be utilized and prepare for the utilization of atomic energy;
 - (c) with the approval of the Governor in Council acquire or cause to be acquired by purchase, lease, requisition or expropriation, prescribed substances and any mines, deposits or claims of prescribed substances and patent rights relating to atomic energy and any works or property for production or preparation for production of, or for research or investigation with respect to, atomic energy;
 - (g) with the approval of the Committee, disseminate or provide for the dissemination of information relating to atomic energy to such extent and in such manner as the Board may deem to be in the public interest;
 - (h) with the approval of the Governor in Council license or otherwise make available or sell or otherwise dispose of discoveries, inventions and improvements in processes, apparatus or machines, patent rights and letters patent

* From *Prospecting for Uranium in Canada*, published by Department of Mines and Technical Surveys, Ottawa, 1952.

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- of Canada or foreign countries acquired under this Act and collect royalties and fees thereon and payments therefor; and
- (i) without limiting the generality of any other provision of this Act, establish, through the Honorary Advisory Council for Industrial and Scientific Research as defined in the Research Council Act, or otherwise, scholarships and grants in aid for research and investigations with respect to atomic energy, or for the education or training of persons to qualify them to engage in such research and investigations.
9. (1) The Board may with the approval of the Governor in Council make regulations,—
 - (c) respecting mining and prospecting for prescribed substances;
 - (d) regulating the production, import, export, transportation, refining, possession, ownership, use or sale of prescribed substances and any other things that in the opinion of the Board may be used for the production, use or application of atomic energy;
 - (e) for the purpose of keeping secret information respecting the production, use and application of, and research and investigations with respect to, atomic energy, as in the opinion of the Board, the public interest may require; and
 - (g) generally as the Board may deem necessary for carrying out any of the provisions or purposes of this Act.
 10. (1) The Board may with the approval of the Governor in Council,—
 - (a) procure the incorporation of any one or more companies under the provisions of Part I of The Companies Act, 1934, for the objects and purposes of exercising and performing on behalf of the Board such of the powers conferred upon the Board by paragraphs (a), (b), (c) and (h) of section eight of this Act as the Board may from time to time direct and all the issued shares of the capital stock of each such company shall be owned or held in trust by the Board for His Majesty in right of Canada except shares necessary to qualify other persons as directors; or
 - (b) assume, by transfer to the Board in trust for His Majesty in right of Canada of all the issued share capital thereof except shares necessary to qualify other persons as directors, the direction and control of any one or more existing companies incorporated under the provisions of Part I of The Companies Act, 1934, all the issued share capital of which is owned by or held in trust for His Majesty in right of Canada except shares necessary to qualify other persons as directors and may delegate to any such company any of the powers conferred on the Board by paragraphs (a), (b), (c) and (h) of section eight of this Act.
 - (2) Every company shall keep and maintain such books and records, in addition to those required by The Companies Act, 1934, as the Board may prescribe and shall make such reports and returns to the Board as the Board may require.
 - (3) The accounts of a company shall be audited by the Auditor General.
 14. Whenever any property has been requisitioned or expropriated under this Act and the compensation to be made therefor has not been agreed upon, the claim for compensation shall be referred by the Minister of Justice to the Exchequer Court.
 20. Any person who contravenes or fails to observe the provisions of this Act or of any regulation made thereunder shall be guilty of an offence and shall be liable on summary conviction to a fine not exceeding five thousand dollars or to imprisonment for a term not exceeding two years or to both fine and imprisonment, but such person may, at the election of the Attorney General of Canada or of the province in which the offence is alleged to have been committed, be prosecuted upon indictment, and if found guilty shall be liable to a fine not exceeding ten thousand dollars or to imprisonment for a term not exceeding five years or to both fine and imprisonment; and where the offence has been committed by a company or corporation every person who at the time of the commission of the offence was a director or officer of the company or corporation shall be guilty of the like offence if he assented to or

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acquiesced in the commission of the offence or if he knew that the offence was about to be committed and made no attempt to prevent its commission, and in a prosecution of a director or

officer for such like offence, it shall not be necessary to allege or prove a prior prosecution or conviction of the company or corporation for the offence.

EXTRACTS RELATING TO PROSPECTING AND MINING FOR URANIUM AND THORIUM FROM THE ATOMIC ENERGY REGULATIONS OF CANADA (REGULATIONS OF THE ATOMIC ENERGY CONTROL BOARD MADE UNDER THE ATOMIC ENERGY CONTROL ACT, 1946, NOVEMBER 3, 1949)*

101. Interpretation

- (1) In these regulations, unless the context otherwise requires:
- (a) "Act" means The Atomic Energy Control Act, 1946;
 - (b) "atomic energy" means all energy of whatever type derived from or created by the transmutation of atoms;
 - (c) "Board" means the Atomic Energy Control Board established by the Act;
 - (d) "deal in" includes produce, import, export, possess, buy, sell, lease, hire, exchange, acquire, store, supply, operate, ship, manufacture, consume and use;
 - (e) "fissionable substance" means any prescribed substance that is, or from which can be obtained, a substance capable of releasing substantial amounts of energy by nuclear chain reaction;
 - (f) "member" means a member of the Board;
 - (g) "order" means any general or specific order, licence, permit, direction or instruction made, given or issued by or under the authority of the Board;
 - (h) "person" includes firm, corporation, company, partnership, association or any other body and the heirs, executors, administrators, receivers, liquidators, curators and other legal representatives of such person according to the laws of that part of Canada applicable to the circumstances of the case, and includes any number of persons acting in concert or for a common purpose;
 - (i) "prescribed equipment" means any property, real or personal, other than

- prescribed substances, that in the opinion of the Board may be used for the production, use or application of atomic energy;
- (j) "prescribed substances" means uranium, thorium, plutonium, neptunium, deuterium, other elements of atomic number greater than 92 and radioactive isotopes of other elements and any substances containing any of the said elements or isotopes;
 - (k) "President" means the President of the Board;
 - (l) "produce" includes develop, drill for, mine, dredge, dig, sluice, mill, extract, concentrate, smelt, refine, purify, separate, enrich and process;
 - (m) words of one gender include all other genders.
 - (2) Elements of atomic number greater than 92, radioactive isotopes of other elements and substances containing any of the elements or isotopes mentioned in paragraph (j) of subsection one of this section are designated as being capable of releasing atomic energy.
 - (3) The Interpretation Act is applicable to and in respect of every order.
 - (4) The grammatical variations and cognate expressions of a word defined in these regulations shall have meanings corresponding to the meaning of the word so defined.

200. Prescribed Substances and Prescribed Equipment Generally

- (1) No person shall deal in any prescribed substance or prescribed equipment except under and in accordance with the

* From *Prospecting for Uranium in Canada*, published by Department of Mines and Technical Surveys, Ottawa, 1952.

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provisions of these regulations or of an order.

- (2) Where any person controls or directs any dealings by any other person in prescribed substances or prescribed equipment, whether such control is exercised through share ownership, trusteeship, agreement, duress or otherwise howsoever, all dealings in prescribed substances or prescribed equipment by such other person may be treated, for the purpose of these regulations or of any order, as dealings by the person who controls or directs such dealings.

- (3) Any order may

- (a) Impose conditions as to furnishing information, preventing disclosure of information, control of, disposition of, price of, inspection of, access to or protection of any prescribed substance or prescribed equipment, or otherwise in relation to any prescribed substance or prescribed equipment;

- (b) regulate, fix, determine or establish the kind, type, grade, quality, standard, strength, concentration, or quantity of any prescribed substance or prescribed equipment that may be dealt in under the order or that may be dealt in by any person either generally or for any specified use and either generally or within a specified period of time.

201. Continued Possession

No order shall be necessary to authorize the continued possession by any person of any prescribed substance (whether or not in such quantity or concentration that an order would be required to authorize other dealings therein) or prescribed equipment acquired prior to the date of the coming into force of these regulations, if full information as to the nature, kind, location, ownership, possession and use or intended use of such prescribed substance (if in such quantity or concentration that an order would be required to authorize other dealings therein) or prescribed equipment is furnished to the Board within 60 days after the said date.

202. Uranium

- (1) No order shall be necessary to authorize

dealings within Canada by any person as regards uranium

- (a) contained in any substance that contains less than 0.05 per cent by weight of the element uranium; or
- (b) contained in any substance and which dealings do not involve during any calendar year a total of more than 10 kilograms of contained uranium element.
- (2) Nothing in this section shall authorize any dealings in any substance that contains any of the uranium isotope U-233 or that contains uranium having any greater percentage of the isotope U-235 than is normally found in nature.

203. Thorium

No order shall be necessary to authorize dealings within Canada by any person as regards thorium

- (a) contained in any substance that contains less than 0.05 per cent by weight of the element thorium; or
- (b) contained in any substance and which dealings do not involve during any calendar year a total of more than 10 kilograms of contained thorium element.

204. Radioactive Isotopes

- (1) No order shall be necessary to authorize dealings within Canada by any person as regards radioactive isotopes of elements of atomic number less than 90 contained in any substance if such dealings do not involve buying, selling, leasing or hiring.
- (2) No order shall be necessary to authorize dealings by any person as regards radioactive elements of atomic number less than 80 contained in any substance that does not contain any greater percentage of any radioactive isotope of any such element than is normally found in nature.

300. Records

Every person dealing in any prescribed substance (otherwise than as may under Part II of these regulations be done without an order) or in any prescribed equipment shall

- (a) keep fully and accurately such books, accounts and records as are necessary adequately to record all dealings by such person in or with any prescribed

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substance or prescribed equipment including such books, accounts and records as may from time to time be required by order;

- (b) furnish to the Board in such form and within such time as may from time to time be required by order such information as the Board may deem necessary in relation to the dealings of such person in any prescribed substance or prescribed equipment;
- (c) produce to any person authorized in writing for the purpose by the Board all or any books, records and documents in the possession or control of such person; and
- (d) permit the person so authorized to make copies of or take extracts from the same and, if so authorized by the Board, to remove and retain any such books, records and documents.

301. Prospecting

Every person not operating under an order who finds in situ any mineral deposit that he believes or has reason to believe contains more than 0.05 per cent by weight of the element uranium, or more than 0.05 per cent by weight of the element thorium, shall forthwith notify the Board of the place of origin and character of such mineral, together with all other information in the possession of such person indicative of the character, composition and probable extent of deposits containing uranium or thorium at or near the place of origin of such mineral.

302. Assaying and Analysis

- (1) Every person who otherwise than
- (a) on behalf of a person operating under an order and as incident to a dealing permitted by such order; or
- (b) as incident to a dealing authorized under Part II of these regulations to be done without an order performs any assay or analysis of any material that indicates that such material contains more than 0.05 per cent by weight of the element uranium or more than 0.05 per cent by weight of the element thorium shall forthwith report to the Board full particulars relating thereto including the name of the per-

son from whom such material was received, the purpose of the assay or analysis, the origin of the material so far as known to the person making the report, and the results of the assay or analysis, and shall not disclose, except to the Board, the result of such assay or analysis, until otherwise directed or permitted by order.

- (2) Every person who, otherwise than on behalf of a person operating under an order and as incident to a dealing permitted by such order, performs any assay or analysis of any material that indicates that such material contains any plutonium, neptunium or other element of atomic number greater than 92 or any uranium containing any of the isotope U-233 or any greater proportion of the isotope U-235 than is normally present in nature shall retain such material and shall not disclose, except to the Board, the result of such assay or analysis until otherwise directed or permitted by order.

303. Import and Export

No person shall import into Canada or export from Canada any prescribed equipment for the time being specified by order for the purposes of this section or any prescribed substance without first producing to the Collector of Customs and Excise at the proposed port of entry or exit an import or export permit from the Board, and no Collector of Customs and Excise shall permit any such prescribed equipment or any prescribed substance

- (a) to be released for delivery to an importer in Canada; or
- (b) to be exported from Canada, unless the appropriate permit from the Board is produced to him.

304. Assistance by other authorities

Where a person by virtue of any statute or order or regulation thereunder has power to obtain information relating to prescribed substances or prescribed equipment

- (a) such person shall if so requested by the Board exercise that power for the purpose of assisting the Board to obtain such information; and

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- (b) any such information possessed or obtained by such person whether upon a request of the Board or otherwise shall, upon the request of the Board, be communicated to the Board.

305. Inspection

Every person dealing in or who proposes to deal in any prescribed substance or prescribed equipment shall permit the Board or any person thereunto authorized by the Board

- (a) to enter any land, premises or place where such dealing is or is proposed to be carried on; and
- (b) to inspect and control such prescribed substance, prescribed equipment or dealing in such prescribed substance or prescribed equipment to such extent as may in the opinion of the Board be necessary to ensure compliance with the terms of these regulations and of any order relating thereto.

306. Disclosure of Information by Board

No information with respect to an individual business that has been obtained by the Board under or by virtue of these regulations or of an order shall be disclosed without the consent of the person carrying on such business, except

- (a) to a department of the Government of Canada or of a province or to a person authorized by such department requiring such information for the purpose of the discharge of the functions of that department; or
- (b) for the purposes of any prosecution for an offence under the Act or these regulations.

600. Expropriation

The Board may with the approval of the Governor in Council enter on and acquire by expropriation any mines, deposits or claims of prescribed substances and any works or property (not being chattel property) for production or preparation for production of, or for research or investigation with respect to, atomic energy in the same manner that the minister (as defined in the Expropriation Act) may enter on and acquire by expropriation land (as defined in the Expro-

priation Act); and all the provisions of the Expropriation Act shall apply in relation to such entry and acquisition by the Board as if the words "department" and "minister" were defined in the said Act as including the Board and the words "public work" or "public works" were defined in the said Act as including the mines, deposits, claims, works and property hereinbefore in this section mentioned; provided, however, that where compensation to be made in respect of any such entry or acquisition has not been agreed on, the claim for compensation shall be referred by the Minister of Justice to the Exchequer Court.

601. Requisition

- (1) The Board may with the approval of the Governor in Council requisition the title to, or any interest in, any prescribed substance and any patent rights relating to atomic energy and any works or property (other than real or immovable property) for production or preparation for production of, or for research or investigation with respect to, atomic energy, by serving the owner or the person in possession thereof, with notice of the Board's intention to requisition the title to or any specified interest in such prescribed substance, patent rights, works or property, or if no Canadian address of the owner or person in possession thereof is known to the Board, by taking possession of, or posting a notice of the Board's intention to requisition on, such prescribed substance, works or property, or in the case of patent rights by filing with the Commissioner of Patents a notice of the Board's intention to requisition such patent rights.
- (2) The Board may use or deal with, or authorize the use or dealing with, or hold, sell or otherwise dispose of, any property requisitioned under subsection 1 of this section as if it were the owner thereof, or of the interest therein specified in the notice.
- (3) The compensation to be made for any property or interest therein, if not agreed upon, shall be referred by the

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Minister of Justice to the Exchequer Court and shall be paid to such person and upon such terms as the Exchequer Court shall direct, and upon such payment being made, His Majesty and the Board and all persons acting under authority of the Board shall be discharged from all liability in respect of such requisition.

800. Exercise of Powers

- (1) Any order authorized by these regulations may be made by the Board, by any such officer or member of the Board or other person as the Board may designate.
- (2) Every order made under these regulations shall be final and binding unless

and until it has been reviewed and varied or vacated by the Board.

802. Service and Publication of Orders

- (1) Any order may be served on any person by sending a copy of such order by registered post to the last known residence or place of business of such person or if such person is a corporation by so sending it to the head office or to any branch or place of business of such corporation in Canada.
- (2) The Board may cause any order made under these regulations to be published in the Canada Gazette and every person shall be deemed to have had notice of such order as from the date of publication of the issue of the Canada Gazette in which it appears.

MANUFACTURERS AND/OR DISTRIBUTORS OF COUNTERS IN CANADA

Canadian Aviation Electronics Ltd.
387 Sutherland Avenue
Winnipeg, Manitoba

Central Scientific Company of Canada Ltd.
146 Kendall Avenue
Toronto 4, Ontario

Douglas Foster
1316 Commercial Drive
Vancouver, B. C.

Electronic Associates Ltd.
2760 Yonge Street
Toronto 12, Ontario

Fisher Scientific Company Ltd.
Montreal, Quebec

Nichols Ltd.
2781 Dufferin Street
Toronto, Ontario

Nuclear Enterprises, Incorporated
1124 Grosvenor Avenue
Winnipeg, Manitoba

Philips Industries Ltd.
Philips House
1203 Philips Square
Montreal 2, Quebec

Sharpe Instruments
188 George Street
Toronto, Ontario

X-Ray and Radium Industries, Ltd.
261 Davenport Road
Toronto 5, Ontario

INFORMATION ON CANADA

ELDORADO MINING AND REFINING (1944) LIMITED PROSPECTORS' AGREEMENT

THIS AGREEMENT made in duplicate this

day of

A. D., 195

BETWEEN:

ELDORADO MINING AND REFINING (1944) LIMITED
(hereinafter called "the Company")

of the one part.

- and -

- and -

(hereinafter called "the Prospectors")

of the other part.

WHEREAS the Company has agreed to engage the Prospectors to prospect and explore for minerals on behalf of the Company for the period and under the conditions hereinafter specified;

AND WHEREAS the Prospectors have agreed to enter the employment of the Company as Prospectors for the period and under the conditions hereinafter specified, and to devote their full time and energy in the said work, and be subject to the Company's direction while so employed;

NOW THEREFORE THIS AGREEMENT WITNESSETH THAT in consideration of the mutual covenants and agreements hereinafter provided the parties hereto undertake and agree as follows:-

(1) The Company hereby engages and employs the Prospectors to prospect and explore for minerals with particular reference to radioactive substances in such territory and in such areas as may be designated by the Company during the 195..... season commencing on the day of A.D., 195..... and ending at such time in that year as may be designated either in writing or by word of mouth by the Company, it being understood and agreed that the Company may terminate the employment of the Prospectors at any time without showing cause on thirty days' notice either in writing or by word of mouth.

(2) The Prospectors hereby enter into the employment of the Company and undertake to act faithfully and diligently as employees of the Company in prospecting and exploring for minerals and ores in the designated territory with particular reference to radioactive substances, acting at all times under the direction of the Company as may be given to them by word of mouth or otherwise from time to time by the Company. In particular the Prospectors undertake and agree to:

- (a) Stake out and record with full compliance with all local requirements all discoveries which appear promising to them or which the Company requests the Prospectors to stake out and record. Unless the Company requests otherwise, the staking of such discoveries shall consist of a group of not less than nine (9) and not more than twelve (12) claims around a discovery or series of adjacent discoveries in an area.
- (b) Report verbally or in writing to the Company from time to time on all their activities and discoveries while in the employ of the Company.
- (c) Execute transfers to the Company of all claims and recordings made by them while in the employ of the Company, or to which the Company is entitled, as the Company may require.
- (d) Refrain from divulging to any person other than the Company any information with respect to promising discoveries of minerals or ores while in the employ of the Company.
- (e) Act as trustees of the Company and give the Company full and complete benefit of all their knowledge and discoveries of promising ore bodies of which they may acquire knowledge or indication, while in the employ of the Company, and refrain from staking any claims for themselves, directly or indirectly, or for any person other than the Company, while in the employ of the Company.

(3) All mining claims, mines, ores and minerals including radio-active substances staked, discovered, obtained or recorded by the Prospectors during their employment by the Company, and all information and reports on the designated territory shall be the absolute property of the Company. The Prospectors hereby agree that they will observe and respect this right of the Company to the full benefit of all their efforts as Prospectors during their period of employment by the Company, and will take all steps necessary to give good title to the Company in all claims and discoveries made during their period of employment.

(4) The Company undertakes to pay the Prospectors in full remuneration, compensation and reimbursement as follows:-

- (a) During the period of employment as hereinbefore specified salaries at the following monthly rates, namely:

To..... as Prospector

\$.....

To..... as Prospector

\$.....

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- (b) During the period of employment as hereinbefore specified the field expenses and travelling expenses to and from the designated territory of each Prospector.
- (c) All licenses, staking and recording fees paid by the Prospectors and required for the purposes of this Agreement.
- (d) With respect to any group of claims which have been staked by the Prospectors and transferred to the Company as hereinbefore provided,
 - (i) An immediate payment of One Thousand Dollars (\$1,000.00);
 - (ii) Annual payments commencing one year after the staking of the said group of claims equal to ten per cent (10%) of the amount expended by the Company during the preceding year in the development of the said group of claims, which further payments shall be not less than One Thousand Dollars (\$1,000.00) per year, and shall continue up to but not beyond the date when production from the said group of claims commences, and in no case shall the total of such annual payments exceed Twenty Thousand Dollars (\$20,000.00), in respect of said group of claims, provided that such payments shall cease upon abandonment of the said group of claims by the Company;
 - (iii) When production from the said group of claims commences, royalty payments of two cents (2c) per pound of uranium oxide contained in the final milled product of the ore taken from the said group of claims, the total of such royalty payments not to exceed One Hundred and Fifty Thousand Dollars (\$150,000.00). It is understood and agreed that the said royalty payments will be based on uranium oxide contained in the final product of the mill.
 - (iv) A royalty equal to ten per cent (10%) of the net profits as certified by the Auditor General of Canada earned by the Company from the sale of metals or minerals, or concentrates containing metals and minerals, other than radioactive substances recovered from the ores taken from the said group of claims, up to a total of One Hundred and Fifty Thousand Dollars (\$150,000.00), such royalty payments to cease when the total payments to the Prospector hereunder reach One Hundred and Fifty Thousand Dollars (\$150,000.00).
- (5) It is understood and agreed by the parties hereto that the Company shall not be under any obligation or liability to do any representation work on any discoveries or claims uncovered or staked by the Prospectors, nor otherwise in any manner whatsoever maintain such discoveries or claims in good standing, nor develop or exploit them, and may abandon any claims at any time as decided by the Company in its sole discretion without notice to the Prospectors. Upon abandonment of any group of claims the Company's obligations to pay annual payments or royalty in respect thereto under paragraph 4(d) of this Agreement shall cease.
- (6) It is understood and agreed by the parties hereto that the Company shall at all times be free to sell, transfer or lease any discoveries or claims staked by the Prospectors and transferred to the Company, or to sell, transfer or lease any part thereof at any time. In the event of any such sale, transfer or lease the Company's obligation to pay annual payments or royalties in respect of the discoveries or claims so sold, transferred or leased under paragraph 4(d) of this agreement shall cease but the Company shall by contract require that the purchaser, transferee or lessee shall undertake to pay the Prospectors annual payments or royalties similar to those provided under paragraph 4(d) of this agreement.
- (7) The Company may act herein in all matters by its Director of Exploration for the time being.
- (8) The Prospectors agree that all monies payable to them, under paragraph 4(d) shall be divided among them in the following proportions:

| | |
|----|---|
| To | % |
| To | % |

The Company is hereby authorized by the Prospectors to make payments to them accordingly, and payments by the Company pursuant hereto shall be deemed full and complete settlement by the Company of its obligations to the Prospectors, jointly and severally.

IN WITNESS WHEREOF the parties hereto have hereunto set their corporate seal and hands and seals respectively.

SEALED, ATTESTED AND DELIVERED
by the proper officers of
Eldorado Mining and Refining (1944) Limited

SIGNED, SEALED AND DELIVERED
by the above-named Prospectors
in the presence of:

ELDORADO MINING AND REFINING (1944) LIMITED

per.....
PRESIDENT

per.....
SECRETARY-TREASURER

Valid only when countersigned by the Company's Director of Exploration.

DIRECTOR OF EXPLORATION.

Appendix XIII—Information on Australia

FACTS ABOUT URANIUM MINING IN THE NORTHERN TERRITORY*

GENERAL CONDITIONS

1. The conditions governing prospecting for uranium and mining for uranium are generally the same as those which apply to prospecting and mining for other minerals. They are included in the Mining Ordinance 1939-1953. Special provisions relating to uranium are that—

- (a) The Administrator may forfeit a uranium mining lease if the development of it is not being carried out to his satisfaction, and
- (b) uranium products must be sold to the Commonwealth or its authorized agents.

Information about the procedure to be followed to obtain claims, leases, etc., can be obtained from the Department of Mines, Darwin or Alice Springs or at the office of a Mining Registrar.

INFORMATION ABOUT URANIUM-BEARING ORES

2. Intending prospectors should read "Pamphlet No. 3—Radio-Active Mineral Deposits," issued by the Bureau of Mineral Resources, Chancery House, 485 Bourke Street, Melbourne, which contains much valuable information. Copies can be secured from the Bureau at Melbourne or Canberra, from the Department of Mines, Darwin and Alice Springs, or from the Department of Mines of any State. The conditions governing rewards, as set out in the Public Notice reproduced on pages 37 and 38 of that pamphlet are, however, now superseded. The latest conditions are shown in paragraphs 26 to 29.

WHO MAY SEARCH FOR URANIUM

3. Anyone can search for uranium just as anyone can search for gold or any other mineral.

WHAT AUTHORITY IS NECESSARY

4. Except in the case of a lease, it is first necessary to obtain a Miner's Right which confers the various privileges described in Section 23 of the Mining Ordinance. Thus, if it is desired to secure an area to prospect for uranium on any Crown

land, a Miner's Right should be obtained at the nearest Mining Registrar's Office. This can be secured by post by forwarding 5/- and stating the full name of the applicant. Having obtained a Miner's Right, the land required should be marked out and an application made to the Mining Registrar for a prospecting area. This will entitle the holder to prospect and test the area with a view to applying for a lease or claim if the area is found to contain uranium ore of saleable grade.

MINING AREAS

5. The three types of mining areas available in the Northern Territory for mining purposes are described in paragraphs 6 to 16.

PROSPECTING AREAS

6. These are limited in area to twenty acres and are the simplest type of mining area. Every prospecting area must be registered and the procedure for registration is as follows. After pegging the area and placing the Notice of Pegging (Form 20) on the Datum post, an application form (Form 21) with a fee of 10s. should be forwarded to the nearest office of the Mining Registrar. The Mining Registrar will then forward to the applicant a Notice of Application (Form 22), which has to be placed on the Datum peg. If no objections are received within a stated period (generally one month), the Warden will consider the application and, if everything is in order, the Prospecting Area will be granted.

7. Prospecting Areas can only be pegged by the holder of a Miner's Right and can only be issued for one year. The Warden can require that a lease be applied for if over 50 tons of ore are mined. This ore can be removed and sold. A Prospecting Area is not surveyed and no rents are charged. The only fee is the registration fee of 10s. mentioned in paragraph 6.

8. Certain labour conditions are imposed. These require that bona fide work in prospecting shall be carried on on every working day after the area is granted and also that one man shall be engaged where the

* Australian Atomic Energy Commission, November, 1953.

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area is less than 10 acres and two men where the area exceeds 10 acres.

MINERAL CLAIMS

9. Mineral claims of up to 80 acres each may be pegged, and the holder of a Miner's Right may apply for any number of claims. For an 80-acre Mineral Claim, the following fees are payable:—

| | £ | s. | d. |
|--------------------------------|-----|----|----|
| Survey Fee..... | 8 | 10 | 0 |
| Registration Fee..... | | 5 | 0 |
| Rent 2s. per acre per annum... | 8 | 0 | 0 |
| Total..... | £16 | 15 | 0 |

The rent is for one year (or less) ending 31st December.

10. Claims are applied for in a similar manner to a Prospecting Area and the same forms are used. Ore can be mined, removed or sold, but, if the mining is extensive, conversion to a lease would probably be required (see paragraph 12).

11. The labour condition imposed in this case is that two men are required for each 80-acre Mineral Claim.

12. The Administrator may, at any time, direct that a Mineral Claim be converted to a Mining Lease.

MINERAL LEASES

13. Mineral Leases for the minerals other than uranium have a maximum area of 40 acres. However, the Administrator may, if necessary, increase this area for a lease for uranium. Leases are pegged in the same manner as Prospecting Areas, but the following procedure applies:—

- (a) Form No. 6 is to be posted on the Datum peg.
- (b) Application Form No. 7 (four copies) is to be forwarded to the Mining Registrar with the following fees for a 40-acre area:—

| | £ | s. | d. |
|------------------|-----|----|----|
| Survey Fee..... | 8 | 0 | 0 |
| Rent..... | 2 | 0 | 0 |
| Advertising..... | 2 | 0 | 0 |
| Total..... | £12 | 0 | 0 |

- (c) After receiving the application, the Mining Registrar will forward Form No. 8 to the applicant, which form

is to be placed on the Datum peg. The Mining Registrar will attend to the advertising.

- (d) After the time allowed for objections has expired, the Warden considers the application and recommends or otherwise the granting of the lease.
- (e) The Administrator determines whether the lease shall be granted.

14. Leases are for a term not exceeding 21 years, subject to payment of annual rent, with a right of renewal. Any person or company can apply for any number of mineral leases.

15. The labour conditions imposed are that, in the first twelve months, one man is to be employed to every 10 acres and, after twelve months, one man is to be employed to every 5 acres, but in no case shall a lease be worked by less than two men.

16. The Administrator may also require the holder of a lease to perform specified developmental work on the lease.

PEGGING A PROSPECTING AREA, CLAIM OR LEASE

17. After a mineral discovery has been located, the ground is taken possession of by pegging. This consists of placing four pegs at the corners of the area desired, generally in the form of a rectangle. The pegs or posts are to be of bush timber, 5 feet to 6 feet long and 3 inches to 4 inches thick, and placed firmly in the ground. If posts cannot be put in, a cairn of stones will do. At each corner post, two trenches are to be dug, 4 feet long by 6 inches wide by 6 inches deep, pointing in the direction of the boundaries. If trenches cannot be dug, a row of stones is allowed.

18. One of the posts is selected as the Datum peg and all notices are tied to this peg. All measurements are commenced and finished at the Datum post.

19. After pegging the ground, the Regulations allow ten days for the application forms to be received by the Mining Registrar, but, in remote localities, the Warden can extend this time if, for any reason, the forms are delayed.

20. The following general notes apply to all pegging:—

- (a) The pegs are to be placed as nearly as possible in the form of a rectangle. The length cannot exceed twice the

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breadth. For a 40-acre area, the sides are 28 and 14 chains. For a 20-acre area, 20 chains by 10 chains. The sketch sent in should show the location of the area in relation to some prominent landmark or existing lease.

- (b) Mines Department Inspectors and other officers will be pleased to assist miners to fill in the necessary papers and, particularly, to locate the area correctly.

ABORIGINAL RESERVES

21. Whilst mining on aboriginal reserves is not prohibited, it is subject to the discretion of the Administrator, who may impose special conditions and restrictions.

MINES BRANCH, NORTHERN TERRITORY ADMINISTRATION

22. The Mines Branch, Northern Territory Administration, has its Head Office at Darwin, with local district offices at Alice Springs and Tennant Creek. The offices are equipped with Geiger counters.

23. Inspectors of Mines are practical mining engineers and are qualified to advise on methods of mining to be used and also the best methods of mining a deposit.

24. Exhibition of samples of uranium-bearing rock for the guidance of prospectors has been arranged by the Mines Branch. In addition, maps and reports of old mining centres are available for perusal by miners.

25. All applications for mining areas, including Prospecting Areas, Claims and Leases are handled by the Branch.

REPORTING A DISCOVERY

26. Under Section 36 of the Atomic Energy Act No. 31 of 1953, any discovery of uranium or minerals containing uranium or other "prescribed substances," as defined in Section 5 of that Act must be reported by the discoverer. This report should be sent in writing to—

The Secretary,
Australian Atomic Energy Commission,
Box 5343, G.P.O.,
Sydney.

It should give particulars of the location of the discovery.

REWARDS FOR DISCOVERIES

27. Rewards are payable, in certain circumstances, for the discovery of uranium

deposits which are worth developing. The maximum reward payable is £25,000, tax free, for a deposit of real importance, such as White's deposit at Rum Jungle.

28. To qualify for consideration for a reward, the applicant must—

- (a) lodge a claim with the Secretary, Australian Atomic Energy Commission, Box 5343, G.P.O., Sydney;
- (b) send a sample of ore weighing not less than 5 lb. to the Director of Mines at Darwin or Alice Springs or to the Director, Bureau of Mineral Resources, Chancery House, 485 Bourke Street, Melbourne, clearly labelled with the name and address of the sender.

29. If the sample, on test, is found to contain uranium, the sender will be advised and the find will be then inspected by Commonwealth officers. The result of the sampling and subsequent investigations will determine whether a reward will be paid. Rewards are payable at the absolute discretion of the Minister for Supply and the amount of any reward is dependent upon the economic value and importance of the discovery. Rewards may be paid in instalments as the value of the discovery is progressively proved.

TRANSFER OF LEASES

30. Application may be made to the Director of Mines, Darwin, or at a Warden's office for permission to transfer a mining lease. A transfer fee of one pound (£1) is payable for each lease transferred and Stamp Duty amounting to 5s. on the first £100 and 10s. on each £100 thereafter is payable.

AMALGAMATION OF LEASES

31. Leases can be amalgamated under certain conditions. Information concerning this can be obtained from a Mining Registrar or Mines Department. An amalgamation fee of one pound (£1) is payable for each lease amalgamated.

PROSPECTING AUTHORITY

32. The Administrator may, on application, grant a Prospecting Authority giving the holder the sole right to prospect in a specified area for a specified period of time. The area covered by a Prospecting Authority is not the same as a Prospecting Area mentioned in paragraphs 6, 7 and 8

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of this pamphlet. The fee payable for a Prospecting Authority will be fixed by the Administrator and will be dependent upon the size of the area covered by the Prospecting Authority.

FINANCIAL ASSISTANCE

33. In certain circumstances, the Administrator may advance limited financial assistance for the development of a mining lease.

SALE OF URANIUM ORES AND CONCENTRATES

34. Under the provisions of the Atomic Energy Act, ores and concentrates may be sold only to the Commonwealth Government or its approved agencies.

35. The Commonwealth Government will purchase, through the Australian Atomic Energy Commission, acceptable uranium-bearing ores and concentrates on the following basis:—

- (a) A minimum uranium content equivalent to 0.25% by weight of uranium oxide (U_3O_8) in the ores will normally be required.
- (b) Ore will be received at Rum Jungle and other purchase points to be specified from time to time.
- (c) Special arrangements will be considered for the purchase of ore of lower grade than that specified in (a) above, and the price payable, though based upon the published schedule, will be subject to adjustment in accordance with the circumstances.
- (d) The Government will consider the establishment of central treatment plants in any area where it can be demonstrated that the proven ore reserves on two or more properties are sufficient to justify a treatment plant, but that the reserves in one of the properties will not support a treatment plant.

PRICE SCHEDULE

36. A schedule of prices for uranium-bearing ores and concentrates is included as Appendix "A".

PRICE SCHEDULE IN PAMPHLET NO. 3— RADIO-ACTIVE MINERAL DEPOSITS

37. The details referred to in paragraph 36 above replace those in Appendix 3 of Pamphlet No. 3—Radio-Active Mineral Deposits.

ASSISTANCE AND ADVICE FROM THE BUREAU OF MINERAL RESOURCES

38. The Bureau of Mineral Resources, Geology and Geophysics includes Geological, Geophysical and Mining Engineering Sections. These Sections have been engaged in the search for radio-active mineral deposits during the past six years and at present the search for uranium deposits forms a substantial part of their programme. The Bureau also acts as technical adviser to the Australian Atomic Energy Commission.

FACILITIES AVAILABLE WITHIN THE BUREAU OF MINERAL RESOURCES

39. The Bureau is staffed and equipped to carry out the following operations in the search for uranium deposits:—

(a) *Geological Section*—

Geological surveys.
Examination of uranium prospects.
Advice on prospecting.
Testing of prospects (including trenching, shallow diamond drilling, etc.).
Identification of radioactive minerals.

(b) *Geophysical Section*—

Airborne scintillometer surveys.
Radiometric surveys.
Other geophysical surveys.
Radiometric logging of bore-holes.
Radiometric assaying of specimens and samples.
Advice on radiometric instruments and techniques.
Investigation of radiometric techniques and instruments.

(c) *Mining Engineering Section*—

Diamond drilling.
Underground testing (shafts, drives, etc.).
Advice on development and mining of deposits and treatment of ores.

40. Apart from its own operations, the Bureau will be prepared to assist miners, prospectors, etc., in the Northern Territory in the ways to be described in paragraphs 41 to 58. Request for such assistance should be made, unless otherwise stated, to (a) the Senior Geologist (Uranium), Bureau of Mineral Resources, Darwin, (b) geological and geophysical parties in the field, and (c) the Bureau's resident staff at Darwin and Alice Springs.

INFORMATION ON AUSTRALIA

TESTING OF SPECIMENS AND SAMPLES

41. Specimens and samples suspected of containing uranium can be submitted personally to any field officer or to any office of the Bureau or sent to any officer or office for testing for radio-activity by radiometric instruments. It is necessary to state where the sample was found. No test work will be performed on samples where the locality is not described. If the tests are successful, the discovery is to be reported to the Australian Atomic Energy Commission (see paragraph 26).

RADIOMETRIC ASSAYING OF SAMPLES

42. The Bureau has established a Radiometric Laboratory within its Geophysical Laboratory, Melbourne, where samples are assayed for uranium and/or thorium contents. Many types of radiometric equipment are in use, physical methods are developed, and standard samples are made up. Samples from any source could be radiometrically assayed in this laboratory; such samples, with covering letters, should be sent to the Director, Bureau of Mineral Resources, 485 Bourke Street, Melbourne.

43. Arrangements are now being made by the Bureau to establish a well-equipped laboratory at Darwin for routine radiometric assaying; this laboratory will assay samples from anywhere in the Northern Territory. Samples should be addressed to the Senior Geologist, Bureau of Mineral Resources, Darwin.

DETERMINATION OF RADIOACTIVE MINERALS IN SPECIMENS

44. Specimens can be submitted, or forwarded, to any field officer or office for examination and determination of minerals. For many specimens, it may be possible to make satisfactory determinations in the field or office. Specimens not readily determinable will be sent for laboratory determination. The Bureau has good facilities for this type of work in the laboratory of the Geological Section at Canberra; samples should be addressed to the Chief Geologist, Bureau of Mineral Resources, Canberra.

ADVICE ON SELECTION OF RADIOMETRIC INSTRUMENTS

45. The Bureau is in a good position to advise on matters associated with radiometric instruments and techniques and will gladly do so. Advice will be given to any-

one seeking it by either letter or interview from any officer or office of the Bureau.

46. Portable Geiger counters are available from several Australian manufacturers and suppliers. These include:—

Austronic Engineering Laboratories Pty. Ltd.

420 William Street
Melbourne

H. B. Selby and Company Pty. Ltd.
393 Swanson Street
Melbourne

John Harvey, Instruments Company
Box 953, G.P.O.
Sydney

Muller Nuclear Industries (Counter) Pty. Ltd.

675 White Horse Road
Mont Albert, E. 10
Victoria

Philips Electrical Industries Pty. Ltd.
590 Bourke Street
Melbourne.

Prices range from approximately £40 to £100, depending on the type of equipment. The above list is not necessarily exhaustive.

47. Construction of elementary types of Geiger equipment involves no serious difficulties. The Bureau has prepared basic circuits for simple types of equipment and copies of these may be obtained on application to the office of the Bureau.

SERVICING OF RADIOMETRIC EQUIPMENT

48. All types of electronic equipment are subject to breakdown due to failure of components and it must, therefore, be expected that any Geiger equipment will require frequent servicing. While, in most cases, the actual repair involves only the replacement of a defective component, the location of the fault generally requires skilled staff and certain essential test equipment.

49. Arrangements are being made for a small workshop to be established at Darwin with staff and facilities to look after all the Bureau's radiometric equipment used in the northern part of the Northern Territory. This laboratory will also be prepared to test faulty radiometric equipment for prospectors and to give advice concerning its repair.

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50. The Bureau's geophysicists with field parties will render similar assistance. However, for major servicing, such equipment should be returned to the manufacturers.

ADVICE ON PROSPECTING FOR AND EXPLORATION OF DEPOSITS

51. In addition to advice given on these matters in the Bureau's Pamphlet No. 3, "Radio-Active Mineral Deposits—Notes for the Guidance of Prospectors," further advice and information will be given to interested persons. Enquiries can be made from any field or other officer at any office of the Bureau.

EXAMINATION OF PROSPECTS

52. The Bureau is prepared to examine prospects already found by a prospector or other person and also areas from which specimens and samples exhibiting radio-activity have been obtained. The Bureau would make geological and radiometric surveys, conduct a sampling and testing campaign and generally advise on the prospects and, if warranted, the best method of further testing the prospect. Such examinations would have to be fitted into the general programme of the Bureau's parties, but would be made as early as possible.

GEOLOGICAL SURVEYS

53. These would be conducted in connection with the examination of prospects referred to immediately above.

GEOPHYSICAL SURVEYS

54. These would be conducted in connection with the examination of prospects referred to immediately above. These surveys may be either—

- (a) radiometric surveys to detect radio-active minerals at the surface, or
- (b) other types of geophysical surveys to investigate deposits of radio-active minerals beneath the surface by detecting sulphides, magnetic minerals, structures, etc., with which radio-active minerals are associated.

55. In category (a), the Bureau carries out radiometric surveys using airborne instruments, vehicle-borne instruments for continuous traversing, and various types of Geiger counters and scintillometers for hand use.

56. In category (b), the Bureau is

equipped to apply all the usual geophysical methods, including magnetic (ground and air), to detect deposits of magnetic minerals; gravity, to detect mineral deposits heavier or lighter than the enclosing rocks; electrical, for detecting metalliferous deposits, and seismic for detecting sub-surface structure.

DIAMOND DRILLING

57. In special circumstances, it might be possible for the Bureau to assist in testing uranium deposits at depth. Normally, however, this would not be undertaken.

RADIOMETRIC LOGGING OF BORE-HOLES

58. The Bureau has equipment for lowering down bore-holes to determine the width and grade of radio-active materials at different depths. In some types of deposits, the radio-active materials are of such a nature that little or no core can be obtained from bore-holes and, under these conditions, radiometric logging is of great importance in assessing the deposits. The Bureau has been using this technique in its own drilling campaign for some time and would be prepared to assist others by supplying such service. The supply of such service would have to be determined in accordance with its own programme and could be given only when staff and equipment were available.

RESULTS OF AIRBORNE SCINTILLOMETER SURVEYS

59. Airborne scintillometer surveys will be carried out as part of the Bureau's programme and in regions selected by the Bureau. It will not be possible, however, to make surveys of small areas for prospectors, companies, etc.

60. These surveys are carried out at a much greater rate than the anomalies revealed by them can be examined by ground parties. The Bureau will do the "follow-up" work on some of the area covered by the airborne surveys, but the remaining areas will be available for prospecting. To assist the latter work, the Bureau proposes to prepare and issue maps showing the anomalies resulting from the airborne surveys. Copies of the maps will be posted at the offices of Mining Wardens, etc., and, if published, made available to the mining public generally.

INFORMATION ON AUSTRALIA

WARNING

Readers are warned that the procedures for pegging Prospecting Areas, Mineral Claims, Leases and Prospecting Authorities referred to in this pamphlet and the Fees, Stamp Duties, etc., quoted are those current at the date of

publication. These may, of course, be varied from time to time and interested parties should confer with the Northern Territory Mining Authorities when these matters affect them.

Appendix "A"

Australian Atomic Energy Commission

Circular No. 1

SCHEDULE OF PRICES FOR URANIUM-BEARING ORES AND CONCENTRATES

As from 1st July, 1953, the Australian Atomic Energy Commission, on behalf of the Commonwealth Government, will be prepared to buy acceptable uranium ores or concentrates.

2. The conditions of purchase will be:—

(a) *Minimum Grade of Ore*.—A uranium content equivalent to 0.25 per cent by weight of uranium oxide (U_3O_8) in the ores.

(b) *Minimum Size of Parcel*.—10 tons of 1 per cent ore or its equivalent (unless otherwise agreed in specific instances).

(c) *Purchase Point*.—Rum Jungle and any other points which may be notified from time to time.

(d) *Minimum Prices—Guaranteed for Five Years from 1st July, 1953.*

For grades intermediate between those shown, the prices for ore will be based on those specified.

NOTE.—Higher prices may be considered in special circumstances.

(e) *Ores Not Amenable to Treatment*.—The Commission reserves the right to reject ores not readily amenable to treatment.

3. This schedule is designed primarily to encourage the prospecting for and development of uranium deposits, and the price shown will apply up to a limit of 20,000 tons of ore purchased from any one producer in any one year. Where uranium deposits appear likely to produce tonnages of ore in excess of this figure, the purchase conditions will be the subject of negotiation between the producer and the Commission.

4. Special arrangements will be considered for the purchase of ore of grades lower than those specified in paragraph 2

| Grade per cent U_3O_8 | Price per lb. U_3O_8 in ore | | | Minimum price per ton of ore (dry weight) at Purchase Points specified |
|-------------------------------|----------------------------------|----|----|--|
| | £ | s. | d. | |
| 0.25 | 1 | 16 | 0 | 10 |
| 0.3 | 1 | 16 | 0 | 12 |
| 0.4 | 1 | 16 | 0 | 16 |
| 0.5 | 1 | 16 | 0 | 20 |
| 0.6 | 1 | 16 | 0 | 24 |
| 0.7 | 1 | 16 | 0 | 28 |
| 0.8 | 1 | 16 | 0 | 32 |
| 0.9 | 1 | 16 | 0 | 36 |
| 1.0 | 1 | 16 | 0 | 40 |
| 2.0 | 1 | 17 | 0 | 83 |
| 3.0 | 1 | 18 | 0 | 128 |
| 4.0 | 1 | 19 | 0 | 175 |
| 5.0 | 2 | 0 | 0 | 224 |
| 10.0 | 2 | 5 | 0 | 504 |

| Grade per cent U_3O_8 | Price per lb. U_3O_8 in ore | | | Minimum price per ton of ore (dry weight) at Purchase Points specified |
|-------------------------------|----------------------------------|----|----|--|
| | £ | s. | d. | |
| 0.10 | 0 | 14 | 0 | 1 10 0 |
| 0.11 | 0 | 16 | 0 | 2 0 0 |
| 0.12 | 0 | 18 | 0 | 2 10 0 |
| 0.13 | 1 | 0 | 0 | 3 0 0 |
| 0.14 | 1 | 2 | 0 | 3 10 0 |
| 0.15 | 1 | 4 | 0 | 4 0 0 |
| 0.16 | 1 | 5 | 0 | 4 10 0 |
| 0.17 | 1 | 7 | 0 | 5 0 0 |
| 0.18 | 1 | 9 | 0 | 6 0 0 |
| 0.19 | 1 | 11 | 0 | 6 10 0 |
| 0.20 | 1 | 13 | 0 | 7 10 0 |

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above, and the price payable—though based upon the published schedule—will be subject to adjustment in accordance with the circumstances. As a guide to producers, the preceding table gives the prices which, depending upon the location, characteristics and tonnage offering of ores of a grade lower than 0.25 per cent, might be the basis of negotiation.

5. The prices for ore as shown in Appendix 3 of the pamphlet entitled "Pamphlet No. 3—Radio-Active Mineral Deposits," issued by the Bureau of Mineral Resources, Geology and Geophysics, in August, 1948, and revised and re-issued in August, 1951, and reprinted in July, 1952, are cancelled.

6. The Commission will consider the establishment of central treatment plants in any areas where it can be demonstrated that there are proven ore reserves on two or more properties and also where it can be shown that the tonnages from individual properties will not support a milling operation.

7. Sellers will be required to send samples to the buyer for examination and assay before negotiations for purchase are commenced. These samples will be examined and assayed by the buyer free of charge. The buyer will bear the cost of weighing, sampling and assaying all parcels of ore purchased. After the shipment is made, the buyer's weights and assays shall be final for the purpose of settlement.

8. Anyone who has uranium-bearing ore or mechanical concentrates of a grade and quality specified in paragraph 2 may offer

it for delivery to the Commission by letter addressed to:—

The Secretary,
Australian Atomic Energy Commission,
Box 5343, G.P.O.,
Sydney.

Advice as to where samples are to be sent for testing will be furnished by the Commission.

9. Sellers should state in their letters—

- (a) the location of the ore or concentrate offered for sale;
- (b) the character of the material offered, i.e., ore or concentrate;
- (c) the amount of material offered;
- (d) name and address of person making the offer;
- (e) nature of title held for the ground from which the ore has been obtained.

10. The period of five years for which the prices in paragraph 2 are guaranteed may be reviewed upwards from time to time if circumstances warrant this.

11. The Commission is prepared to negotiate with the seller respecting any other mineral which may be present in economic quantities in the uranium-bearing ores purchased by it.

Issued at Sydney this 30th day of June, 1953.

P. C. GREENLAND,
Secretary.

*Appendix XIV—Information on United Kingdom and British Colonial Territories**

GENERAL STATEMENT

The prospector who finds a deposit of radioactive mineral in any country of the British Commonwealth can readily obtain advice on the value of his discovery on communicating with the headquarters of his local Geological Survey. In most countries he is compelled by law to report the discovery; but such legal obligations as may exist are not intended to restrict ex-

ploration and development. All Governments within the Commonwealth are anxious to ensure that everything possible is done to locate and work such uranium and thorium resources as may exist inside their frontiers. The only important prohibition likely to be encountered by a prospector or mining company is that export will not be permitted except under licence—a restric-

* From *A Prospector's Handbook to Radioactive Mineral Deposits*, published by Dept. of Scientific and Industrial Research, London, 1949.

UNITED KINGDOM AND BRITISH COLONIAL TERRITORIES

tion necessary since radioactive ores are required for defence purposes as well as for research into the peaceful applications of atomic energy.

In London the Atomic Energy Division of the Geological Survey has been established to promote the discovery and development of radioactive mineral deposits capable of furnishing uranium and thorium ores to the British Ministry of Supply.¹ The Division will be pleased to report, free of charge, on the radioactivity of any samples of ore, concentrate or mill product believed to contain uranium or thorium and submitted for examination. Samples should normally be about one or two pounds in weight and should be accompanied by a letter giving the fullest possible

details of the location and extent of the deposit (preferably with a sketch-map), the tonnage of which the sample is representative, the nature of the rocks in the area whence the sample was derived, and any other information which seems relevant. It is important that samples should be as representative as possible, and not mere hand-picked specimens. In appropriate cases, where a suitable series of samples shows positive analyses, arrangements may be made for an experienced geologist to make a field appraisal on behalf of Ministry of Supply.¹ Samples should be addressed to the Chief Geologist, Atomic Energy Division, Geological Survey and Museum, London, S.W.7.

THE MARKET FOR URANIUM MINERALS

To promote exploration for radioactive minerals throughout the British Colonial territories, the Ministry of Supply¹ has announced minimum prices for uranium ores, with a guarantee to purchase at these prices all ores of stipulated grade that may be produced up to 1959. The most recent announcement on this subject, dated 2nd November, 1951, is as follows:

PURCHASE OF URANIUM AND THORIUM BY MINISTRY OF SUPPLY¹

1. In March, 1949, the U. K. Ministry of Supply¹ offered to purchase all uranium ores and concentrates produced in Colonial and Dependent territories during the period of ten years from the date of the announcement, at a minimum price of 13s. 9d. per lb. of uranium oxide delivered f.o.b. ocean port. From the date of this announcement this minimum offer is increased to values ranging between £1 5s. 0d. and £1 15s. 0d. per lb. of uranium oxide, c.i.f., according to the grade of the ore.

2. For concentrates containing not less than 10 per cent U_3O_8 , the price offered is now raised to £1 15s. 0d. per lb. of contained uranium oxide, delivered c.i.f. U. K. port.

3. In the original offer of March, 1949, the Ministry did not guarantee to purchase ore or concentrate containing less than 10 per cent U_3O_8 . This reservation is now withdrawn. The Ministry will henceforth

accept ore assaying not less than 0.20 per cent U_3O_8 , the price depending on the grade. For ore of 0.20 per cent content the price will be £1 5s. 0d. per lb. of contained U_3O_8 delivered c.i.f. a specified plant or U. K. port. The price will rise according to the grade of ore, to a value of £1 15s. 0d. for 10 per cent concentrate.

4. This offer is subject to the reservations: (a) that the Ministry does not guarantee to purchase lots containing less than one ton of uranium oxide—e.g., lots of less than 10 tons of 10 per cent concentrate or 500 tons of 0.20 per cent ore; (b) that only pitchblende ores and their secondary derivatives will be bought in this way, no guarantee of purchase being made in respect of refractory uranium ores that are not treatable by simple acid-leaching plants.

5. As a special incentive to the discovery and exploitation of new uranium deposits, the Ministry will pay a development bonus to any person who produces and delivers on the above terms acceptable ore or concentrate containing not less than one ton of uranium oxide, from a concession or mining lease situated in Colonial and Dependent territories and not previously worked for uranium. For the first five tons of uranium oxide so produced and delivered from a new property, the vendor will be eligible for a development bonus equal to the price paid for the ore or concentrates and additional to this price.

¹Now: Department of Atomic Energy, St. Giles Court, St. Giles High Street, London, W.C.2.

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6. The above prices take into account all radioactive elements in the ores or concentrates: but the Ministry will also make allowances for the presence of other valuable constituents (if any), having regard to the cost of recovery.

7. Where the concentrates potentially available from a deposit being worked, or proposed to be worked, are adequate to justify the outlay, the Ministry may provide the capital required for the installation of concentrating plants.

8. No specific offer is made for thorium-bearing minerals; but the Ministry will be ready to discuss terms for purchase from any would-be vendor.

9. It will be noted that the above offer does not apply to uranium in the United Kingdom.

10. Persons having ores or concentrates for sale are invited to communicate with the Ministry of Supply, Division of Atomic Energy, Shell Mex House, London, W.C.2.¹

GEOLOGICAL SURVEY AND MUSEUM
NOVEMBER, 1951

LONDON: HIS MAJESTY'S
STATIONERY OFFICE: 1951

Appendix XV—Sources of Information Outside of the United States

Those wishing additional information on prospecting for or mining uranium, thorium, or beryllium in the following countries or aid in evaluating discoveries made in those countries should contact the organizations listed:

ARGENTINA

Comisión Nacional de la Energía
Atómica
Buenos Aires, Argentina

AUSTRALIA

Australian Atomic Energy Commission
"Cliffbrook"
45 Beach St.
Coogee, N.S.W.
Sydney, Australia

Box 5343, G.P.O.
Sydney, Australia

Bureau of Mineral Resources
Melbourne Building
Canberra, A.C.T.
Australia

485 Bourke St.
Melbourne, C.1.
Australia

or

SOUTH AUSTRALIA

Department of Mines
Flinders St.
Adelaide, South Australia

VICTORIA

Department of Mines
Treasury Gardens
Melbourne, Victoria

QUEENSLAND

Department of Mines
Brisbane, Queensland, Australia

WESTERN AUSTRALIA

Department of Mines
Perth, Western Australia

TASMANIA

Department of Mines
Hobart, Tasmania, Australia

NEW SOUTH WALES

Department of Mines
Sydney, New South Wales, Australia

NORTHERN TERRITORY

Director of Mines
Alice Springs, N.T.
Australia

Darwin, N.T.
Australia

(Also see Appendix XIII)

BELGIUM

Centre d'Études pour les Applications de
l'Énergie Nucleaire
31 Rue Belliard
Brussels, Belgium

¹ Now: Department of Atomic Energy, St. Giles Court, St. Giles High Street, London, W.C.2.

SOURCES OF INFORMATION OUTSIDE OF THE UNITED STATES

BOLIVIA

Comisión Mixta de Minerales Radioac-
tivos
Ministerio de Minas y Petroleos
La Paz, Bolivia

BRAZIL

Cientifico Conselho Nacional de Pesqui-
sas
Ave. Marechal Camara 350, 5° Andar
Rio de Janeiro, Brazil

CANADA

Atomic Energy Control Board
Ottawa, Canada

Mines Branch
Dept. of Mines and Technical Surveys
30 Lydia St.
Ottawa, Canada

Geological Survey of Canada
Dept. of Mines and Technical Surveys
Ottawa, Canada

Eldorado Mining and Refining, Ltd.
P. O. Box 379
Ottawa, Canada

(Also see Appendix XII)

CHILE

Corporacion de Fomento de la Produc-
cion
Santiago, Chile

COLOMBIA

Servicio Geológico Nacional
Ministerio de Minas y Petroleos
Bogotá, Colombia

FRANCE (AND COLONIAL TERRITORIES)

Commissariat de l'Energie Atomique
69 Rue de Varenne
Paris 7, France

GREECE

Institute for Geological and Subsurface
Research
Bouboulinas 20
Athens, Greece

HONDURAS

Ministro de Agricultura
Tegucigalpa, Honduras

INDIA

Atomic Energy Commission
Government of India
North Block, Secretariat
New Delhi, India

MEXICO

Instituto Nacional de Recursos Minerales
Av. Marelos 110-207
Mexico, D. F.

Comision de Fomento Minero
San Juan de Letran 21
Mexico, D. F.

NEW ZEALAND

Dept. of Scientific and Industrial Re-
search
Government Buildings
P. O. Box 8018
Wellington C. 1., New Zealand

Geological Survey
156 The Terrace
Wellington, New Zealand

NICARAGUA

Ministro de Fomento
Managua, Nicaragua

NORWAY

Institute of Atomic Energy
Oslo, Norway

PERU

Instituto Nacional de Fomento e Inves-
tigaciones Mineras
Lima, Peru

Banco Minero del Perú
Apartado No. 2565
Lima, Peru

Junta de Control de Sustancias Radioac-
tivos
Lima, Peru

PHILIPPINE ISLANDS

Bureau of Mines
Herau Street
Manila, P. I.

PORTUGAL

Comissão de Estudos da Energia Nu-
clear
Lisbon, Portugal

Ministerio da Economia
Direcção-Geral de Minas e Servicos Geo-
logicos
Lisbon, Portugal

SPAIN

Junta de Energia Nuclear
Ser-ano 121
Madrid, Spain

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SWEDEN

Swedish Atomic Energy Committee
Stockholm, Sweden

TURKEY

M.T.A. Enstitüsü
Ankara, Turkey

UNION OF SOUTH AFRICA

Government Mining Engineer
P. O. Box 1132
Johannesburg, Union of South Africa

Geological Survey
Atomic Energy Board
P. O. Box 401,
Pretoria, Union of South Africa

UNITED KINGDOM (AND COLONIAL TERRITORIES)

Atomic Energy Division
Geological Survey and Museum
London, S.W.7, England

Department of Atomic Energy
St. Giles Court
St. Giles High St.
London, W.C.2, England

(Also refer to the local Geological Survey
in Colonial territories.)

VENEZUELA

Dirección Técnica De Geología
Ministerio de Minas e Hidrocarburos
Caracas, Venezuela

*Appendix XVI—Convenient Conversion Factors**

HEAT ENERGY IN URANIUM

The Fissioning of All the U-235 in

- 1 gram of U_3O_8 yields 47.4×10^4 BTU (139 kw-hr) as heat
- 1 pound of U_3O_8 yields 223×10^6 BTU (65.5×10^3 kw-hr) as heat
- 1 ton of U_3O_8 yields 447×10^9 BTU (131×10^6 kw-hr) as heat
- 1 gram of natural uranium yields 55.9×10^4 BTU (164 kw-hr) as heat
- 1 pound of natural uranium yields 267×10^6 BTU (78.2×10^3 kw-hr) as heat
- 1 ton of natural uranium yields 532×10^9 BTU (156×10^6 kw-hr) as heat
- 1 gram of U-235 yields 78.4×10^6 BTU (23×10^3 kw-hr) as heat
- 1 pound of U-235 yields 36.8×10^9 BTU (10.8×10^6 kw-hr) as heat
- 1 ton of U-235 yields 73.7×10^{12} BTU (21.6×10^9 kw-hr) as heat

URANIUM-COAL EQUIVALENTS¹

The Fissioning of All the U-235 in

- 1 pound of U_3O_8 will release the same amount of heat as 6.5 tons of coal
- 1 pound of natural uranium will release the same amount of heat as 11 tons of coal
- 1 pound of U-235 will release the same amount of heat as 1,530 tons of coal

ELECTRIC POWER EQUIVALENTS

At 20% over-all power plant efficiency (fuel to electricity) and with the fissioning of all its U-235 . . .

- 1 ton of U_3O_8 would yield 26×10^6 kw-hr of electricity
- 1 ton of natural uranium would yield 31×10^6 kw-hr of electricity
- 1 ton of U-235 would yield 4.3×10^9 kw-hr of electricity

A large, modern steam power plant burning conventional chemical fuel (coal, oil or gas) has an over-all efficiency (fuel to electricity) of 33%.

* J. Wm. Young, Division of Reactor Development, U. S. Atomic Energy Commission, 1953.

¹ The uranium in the U_3O_8 is natural uranium. The coal contains 12,000 BTU per pound.

CONVENIENT CONVERSION FACTORS

MISCELLANEOUS

| | |
|-------------------------|--|
| 1 pound | equals 454 grams |
| 1 kilogram | equals 2.2 pounds |
| 1 kw-hr (kilowatt-hour) | equals 3,410 BTU (British Thermal Units) |
| 1 BTU | equals 6.6×10^{15} mev (million electron volts) |
| 1 kw-hr | equals 2.3×10^{19} mev |

$$\text{Ft lbs energy} = MC^2 = \frac{Wt}{g} C^2$$

$$C^2 = (5280 \times 186,000)^2 = 9.6448 (10)^{17}$$

$$1 \text{ horsepower} = 33,000 \text{ ft-lb per min}$$

$$1 \text{ horsepower-hour} = 1,980,000 \text{ ft-lb per hr}$$

$$1 \text{ kilowatt-hour} = 1.33 \frac{1}{3} \times 1,980,000 = 2.64 (10)^6 \text{ ft-lb per hr}$$

$$g = 32 \text{ ft per sec per sec}$$

One 2000 lb ton natural U_3O_8 contains about 12.11 lb U-235

Total ft lbs of energy released in fission of 12.11 lb pure U-235 means the transformation of a 1/1000 part of this 12.11 lbs into energy.

$$\frac{1}{1000} \left(\frac{12.11 \text{ lb}}{32 \text{ ft per sec}} \right) \times (9.6448)(10)^{17}$$

Total Equiv. Kw-Hr Released

$$\frac{1}{1000} \left(\frac{12.11}{32} \right) \times 9.6448 (10)^{17} \times \left(\frac{1}{2.64(10)^6} \right)$$

$$\text{At } 100\% \text{ Efficiency} = 138 (10)^6$$

$$\text{At } 20\% \text{ Efficiency} = 27.6(10)^6 \text{ kw-hr}$$

U. S. now using about 500 billion kw-hr per yr.

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¹ Numbers in bold-face type refer to the Radioactive Minerals Identification Table; the number in parentheses refers to the number of the mineral in its respective group.

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